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Guided Inquiry Assisted by Scaffolding in Biology Learning: A Solution to Improve Students Critical Thinking and Metacognitive Supporting SDG 4 (Quality Education)

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Abstract: This study purposed to determine the effect of guided inquiry learning assisted with scaffolding on students' critical thinking and metacognitive skills. This quasi-experimental study employed a pretest-posttest control group design. The study was conducted at SMA Negeri 1 Gondang Mojokerto with the research subject being 11th-grade science students, involving a control group using conventional instruction and an experimental group using guided inquiry learning supported by scaffolding. Data were collected through tests, using research instruments in the form of critical thinking and metacognitive essay test. Data were analyzed using the Mann-Whitney test and the N-Gain test. After being implemented with the guided inquiry learning model supported with scaffolding, critical thinking skills increased to 67.45 in the medium category. The results of the Mann-Whitney test showed a significant difference ($p = 0.05$). furthermore, in the N-Gain test analysis, the experimental group scored 57.59 in the moderately effective category, while the control group scored 7.39 in the ineffective category. The analysis of metacognitive skills revealed that the experimental group's metacognitive skills were at 56.30 in the moderately effective category. It means that guided inquiry supported with scaffolding is affective in improving critical thinking and metacognitive skills.

Keywords: Critical thinking; Guided inquiry; Metacognitive; Scaffolding

Introduction

Sustainable Development Goals (SDGs) is a concept of sustainable development in various fields, one of the main focuses is the field of education or education sustainable development (ESD), which aims to develop values, knowledge, skills, and competencies to encourage poverty (Diez-Ojeda et al., 2025). In the era of 21st century learning, every learning activity that is organized oriented to students to train the student skills (Mardhiyah et al., 2021; Redhana, 2019). These 21st century skills consist of critical thinking, creativity, collaboration, and communication skills, there are other skills that also important, such as problem solving and metacognitive (Thornhill-Miller et al., 2023; Shekh-Abed, 2024; Akben, 2020). These skills are not require to memorization, but rather skills focused on solving a problem or give an alternative solution to a problem (Anas & Mujahidin, 2022). Based on preliminary test showed that 90% of students scored below the minimum mastery criterion (KKM), specifically in the human digestive system material, that conducted in class XI Science at Senior High School of 1 Gondang, Mojokerto. It founds that students have several difficulties to understand biology concept, and have low critical thinking and problem solving skill, as seen in their ability such as answer questions with an arguement, analyze a phenomena, and evaluate them.

Based on these problem occur in biology learning at that school. According to Maulidia et al. (2024) in biology learning, students require the high order thinking skills and deep thinking. According to Tanjung

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et al. (2023) and Yurtseven et al. (2022) Many difficulties are encountered when study in biology, caused by abstraction material, which is makes it difficult for students to understand the concept, leading to misconception and requiring scientific explanation and evidence. Therefore, students critical thinking and metacognitive skills needs to be trained.

Critical thinking skills are a complex set of processes involving various skills such as identifying, evaluating, synthesizing, reflecting, and making conclusions, also presenting a structured point of view (Corttrell, 2023). According to Putri et al. (2018), critical thinking skills are essential in biology learning to explore issues more deeply and generate ideas to solve them. However, critical thinking cannot be separated from the role of metacognitive, which is skills of regulating the process of transferring knowledge to problem solving, self-regulated and controlling (Listiana et al., 2016; Craig et al., 2020; Winne & Azevedo, 2022; de Vera, 2023).

There are several factors that influence critical thinking and metacognitive skills, and one of them is the application of learning models (Agustina & Abidin, 2022). The guided inquiry learning model can help students to develop these skills, caused that based on students center learning model, and refers to constructivism learning theory, where students build their knowledge through scientific examination and investigation (Ngalimun, 2017; Maknun, 2020; Kuhlthau et al., 2007). According to Nurlaila et al. (2021) to facilitate cognitive ability gaps resulting from differentiation cognitive ability due to the large number of students, an intervention is needed. Scaffolding is an intervention that integrated to help students difficulties (Belland, 2017; Ronen & Langley, 2019; Yu et al., 2024). Futher explanation by Pol et al.(2015) and Orey (2010) clarified that the use of scaffolding in learning refers to the temporary support provided to help students complete tasks, they might otherwise be unable to accomplish. There are four type of scaffolding such as conceptual, metacognitive, procedural, and strategies (Hannafin et al., 1999).

Recent research shows that the success of guided inquiry learning largerly hinges on the existing knowledge and cognitive preparedness of students. Learners who possess limited prior knowledge frequently face cognitive overload and confusion during inquiry activities, as ther must tackle intricate tasks like forming hypotheses, interpreting data, also employing scientific reasoning (Lazonder & Harmsen, 2016; Zeitlhofer et al., 2024; Kaiser et al., 2018). The study found that the majority of students demonstrated a high or moderate level of metacognitive behavior, indicating proficiency in planning, monitoring, and evaluating their approach to solving problems (Sapulete et al., 2024). The realization of students' metacognition awareness must be encouraged by the teacher (Rahmadhni & Chatri, 2023). Moreover, empirical studies indicate that inquiry-based teaching is generally more benefical for students with moderate to high academic skills, while those with lower cognitive abilities tend to stuggle to gain advantages from such methods unless they receive additional support (Cairns, 2019; Reith & Nehring, 2026). Therefore, critical thinking skills and metacognition awareness are related towards the student's knowledge learning outcomes (Khairinaa et al., 2023).

In this context, scaffolding is essential for enhancing student learning. It offers organized assistance that aids in diminishing cognitive load, guided students' thought processes, and promotes the growth of conceptual understanding (Thomann & Deutscher, 2025). Furthermore, research has demonstrated that scaffolding can greatly enhance learning results and critical thinking abilities, especially for students with limited prior knowledge (Awi et al., 2025). Consequently, incorporating scaffolding into guided inquiry learning is necessary for its effectiveness and to assist a variety of learners in achieving significant educational outcomes.

The novelty of this study presents an innovative combination of guided inquiry learning model, and forms of scaffolding, an approach rarely explore within the context of biology learning in Indonesia. This integrated model objectives to gain the students critical thinking and metacognitive skills. The purpose of this research is to determine the effectiveness of the guided inquiry model integrated with forms of scaffoldings, in train students critical thinking and metacognitive skills in biology learning as 21-st century skills.

Method

This research is a quasi-experiment with a pretest-posttest control group design with two classes (Sugiyono, 2021). The experimental class used a guided inquiry learning model integrated with forms of scaffolding, while the control class used a conventional learning model. The difference between the result of the pretest dan post-test from each class was thought to reflect the effect of the treatment. Each class is taught in four meetings, three meetings for lessons, and one for exam. The research design that will be used is according to Sugiyono (2021) can be seen in Table 1.

Table 1. Pretest-posttest Control Group Design (Sugiyono, 2021)

	Group	Pretest	Variable	Posttest
R	Experiment	O1	X	O2
R	Control	O3		O4

The research population is students of class 11th SMA Negeri 1 Gondang Mojokerto, consist of 9 classes with 315 students. The sampling technique used a simple random sampling technique (Sugiyono, 2021). The research sample was 33 students of class 11th Science 2 as experiment class, and 35 students of class 11th Science 9 as control class.

The critical thinking indicators seen in the competency aspect such as focus, reason, inference, situation, clarity, and overview or namely FRISCO (Ennis, 1991). Metacognitive skills indicators have two components, which are knowledge about cognition such as declarative knowledge, procedural knowledge, and conditional knowledge, and the second is regulation of cognition such as, information management strategies, comprehension monitoring and evaluation (Brown et al., 1982).

The research instrument is used essay test integrated with achievement test given before learning as pretest, and after learning as posttest. The students answer sheets will be evaluated used rubric of critical thinking embedded essay test (CTEE Test) which has been developed by Zubaidah et al. (2020), and rubric for measuring metacognitive skill integrated to essay test of echievement test, which has been developed by Aloysius (2009).

The data analysis technique in this research using descriptive and statistic with significance value α = 0,05. The students answer in the essay test will be processed based on the rubric of CTEE Test to measure their critical thinking, and using the metacognitive skills integrated to essay test of echievement test rubric to measure their metacognitive skills. Then the score that their obtain, will be calculated using the formula 1. The score obtained will be categorized in table 2 and 3.

$$\text{Student grades} = \frac{\text{the score obtained by the student}}{\text{maximum score}} \text{ x } 100\% \quad (1)$$

Table 2. Critical Thinking Essay Test Category (Farcis, 2019)

Range of value (%)	Category
0 – 55	Very low
55 – 64	Less
64 – 78	Medium
78 – 89	High
89 – 100	Very high

Table 3. Metacognitive Essay Test Category

Range of value (%)	Category
0 – 16	Not yet
17 – 33	Risk
34 – 50	Cannot really
51 – 67	Development
68 – 84	Ok

Adapted from Green (2002) in Amin et al. (2020)

To determine the difference in cirtical thinking and metacognitive skills, based on differences in the use of learning model, the difference result between the pretest and post-test, will be analyze statistically, through the following test.

Normality Test

After the research data was obtained, the data normality test was conducted to determine whether the data obtained from the research results was normally distributed or not. This data normality test used the Shapiro-Wilk test in SPSS. If the significance α > 0.05, it means the data its normal.

Homogeneity Test

Variance homogeneity testing aims to test the average similarity of several variances, in this research used Levene test in SPSS, with significance α = 0.05. If the significance > 0.05, it means the data homogene.

N-Gain Test

N-Gain test is the difference between pretest scores and posttest scores. Gain reflects the increase in the ability or mastery of the concept of students after learning. To avoid the results of the author normal conclusions, because the pretest score of the two research groups are already different, the gain test can be calculated using the Hakke equation.

$$\text{N} - \text{gain} = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Ideal score} - \text{Pretest score}} \quad (2)$$

Table 4. N-gain Interpretation

Percentage (%)	Category
<40	Ineffective
40 – 55	Less effective
56 – 75	Moderately effective
>76	Effective

Hakke (1998) in Sukarelawan et al. (2024)

Hypothesis Test

This hypothesis testing aims to determine the difference in critical thinking and metacognitive skills in experimental and control classes. Hypothesis testing in this study uses non-parametric statictical tests with Mann-Whitney test through the SPSS.

Result and Discussion

Based on the research that has been conducted, the following results are obtained: description of the experimental class dan control class.

Critical Thinking

Based on the result of pre-test and posttest, XI-Science 2 and XI-Science 9 had different results. The

following data from the essay test results are presented in Figure 1 to show the critical thinking skill of the students.

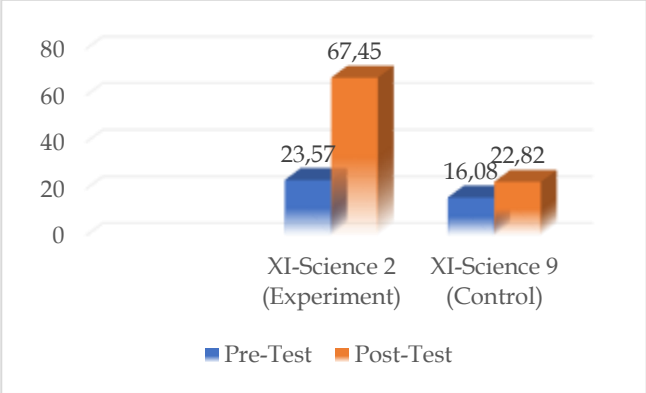

Figure 1. Graph average critical thinking skills based on essay test

Figure 1 shows the average value of students critical thinking skill based on the essay test in each class. It can be seen that the students critical thinking skills on the pretest between experiment class and control class had almost the same average level in very low categorize, 23,57 in the experiment class, and 16,08 in the control class. In final test, the experiment class obtained a higher average score than the control class, 67,45 in the experiment class and it can be categorized in medium level, and 22,82 in the control class can be categorized in very low level. Therefore, it can be seen that the treatment given to the experiment class using the guided inquiry model integrated with forms of scaffolding result in higher levels of critical thinking skills compared to the control class. According to Arends (2015) in guided inquiry learning model, students maybe can explore their skills through investigation, so that they can develop deep thinking, and offer any solution. The integration of forms of scaffolding in guided inquiry learning model, can influence students difficulties and facilitate students understanding, thus can improve their mastery of biological concepts (Weng et al., 2017; Yu et al., 2024). With a good biological concept, students can develop their critical thinking skills.

Guided inquiry integrated with form of scaffolding is more effective in helping students aquire critical thinking skills, because students are actively involved in formulating questions, exploring multiple sources to obtain data, conducting experiments, analyzing the information obtained, and conclude the result from the analysis. The role of the teacher as a facilitator who guides the learning process serve as an intervention or scaffolding for students, thus improving their comprehension.

Metacognitive

Based on the result of pre-test and posttest, XI-Science 2 and XI-Science 9 had a different result. The following data from the essay test results are presented in Figure 2 to show the metacognitive skill of the students.

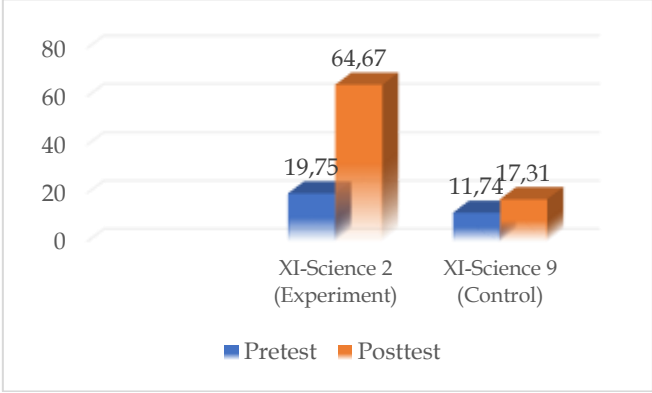

Figure 2. Graph average metacognitive skills based on essay test

Based on the essay test results shown in figure 2 and the categorization of metacognitive essay test score in table 3, it is known that the pretest scores of experimental class obtained an average score of 19.75 which is categorized as "Risk," while the control class obtained an average score of 11.74, which is categorized as "Not yet." However, the average essay test scores on the final test showed a difference between the experimental class and the control class. The experimental class obtained an average score of 64.67, which was categorized as "Development," while the control class obtained an average score of 17.31, which was categorized as "Risk." The difference between the two classes was based on the learning process applied.

Differences in students' metacognitive abilities are influenced by one main factor, namely the use of learning models (Agustina & Abidin, 2022; Rokhman, 2023). According to Li et al. (2022) and Amien et al. (2023), The learning activities in the guided inquiry model have the potential to help students apply metacognitive strategies to develop their own metacognitive abilities. In the data collection stage, students can explore their own knowledge through discovery and experimentation activities, then discuss the results of their exploration, enabling them to compare and evaluate their performance, and ultimately assess their own learning abilities. The integration of scaffolding in the form of questions, directions, and commands in the learning process can encourage students to regulate their thinking skills and problem-solving abilities.

Description of Normality Test

The normality of the pretest and posttest difference, data analyze using the Shapiro-Wilk in SPSS, with significance α= 0.05, when the Sig. value of the experimental and control class, both the pretest and posttest have a greater than 0.05, it means that the data be normally distributed. The results can see on the table 5.

Table 5. Normality Test Result

	Group	Sig.	Conclusion
Critical Thinking	Experimental class	.061	Normal
	Control class	.009	Not normal
Metacognitive	Experimental class	.027	Not normal
	Control class	.848	Normal

Description of Homogeneity Test

The data was test for homogeneity used Levene's test in SPSS, applying significance α= 0.05, when the Sig. value has a greater than 0.05, it means the data homogene. The result is shown on the table 6.

Table 6. Homogeneity Test Result

		Levene's Test Equality of variances	
		F	Sig.
Critical Thinking	Equal variances assumed	1.110	.296
	Equal variances not assumed		
Metacognitive	Equal variances assumed	5.533	.022
	Equal variances not assumed		

Description of Mann-Whitney Test

Based on the data from the Mann-Whitney test results in table 7, it is known that the sig value (2 tailed) is 0.000 < 0.05, which means that there is a significant difference in the critical thinking and metacognitive skills of students who use the guided inquiry integrated scaffolding learning model and those who use the conventional learning model. To see the improvement in students' scientific literacy, the N-Gain test was continued. The N-Gain test results are listed in Table 8.

Table 7. Mann-Whitney Test Result

	Mann-Whitney U	Wilcoxon W	Mann-Whitney Test Z	Sig. (2-tailed0
Critical Thinking	44.500	674.500	-6.545	.000
Metacognitive	40.500	670.500	-6.591	.000

Description of N-Gain Test

The results of the N-Gain test conducted on both classes showed a score of 57.59% in table 8, indicating the effect of the integrated guided inquiry model of scaffolding on students' critical thinking skills. The results obtained can be categorized as "Moderately effective" based on Table 4, also the N-gain test results of 56.30% show the effect of the guided inquiry model integrated with scaffolding on students' metacognitive abilities, which is categorized as "Moderately effective". Based on these results, it can be seen that the use of the guided inquiry learning model integrated with scaffolding forms can improve students' critical thinking and metacognitive skills in biology learning, especially in the topic of the gastrointestinal system.

Table 8. N-Gain Test of Critical Thinking and Metacognitive Result Based on Essay Test

Class	N-Gain Learning Activities	Category	N-gain Learning Activities	Category
Control	7.39	Ineffective	6.20	Ineffective
Experiment	57.59	Moderately effective	56.30	Moderately effective

According to Doyan et al. (2023) the guided inquiry model is a learning model designed to teach concepts and the relationships between concepts in the material, so that with a good grasp of the concepts, critical thinking skills can be trained. Guided learning and teacher intervention in the form of scaffolding can control differentiation in their cognitive abilities. An experiment conducted and an analysis of the experimental results can help students explore their ideas and knowledge more deeply. According to Ibnusaputra et al. (2023) this can reduce the possibility of misconceptions in learning, and develop other thinking skills, such as creative thinking skills (Dani et al., 2021).

In the conventional learning model implemented in the control class, learning activities consist solely of the transfer of information, there are no opportunities for doing investigation, reflection, data collection, or communicating the findings, so they are unable to construct their own knowledge. The lack of students' involvement in the problem-solving process will have an impact on their critical thinking skills. According to Irdalisa et al. (2024) and Selasmawati et al. (2023) conventional learning model remains dominated by teacher-centered approaches, so students' exploration of knowledge is limited, so that their critical thinking skills cannot be trained.

Due to conventional learning method still being dominated by lectures and teacher-centered instruction, students become passive and lack the opportunity to monitoring their own understanding, evaluating their learning strategies, and reflecting on their thought processes and developing questioning skills. All of these factors result in metacognitive abilities that cannot develop optimally. Passive information reception and a focus on transferring materials make it difficult for students to apply their metacognitive strategies, so that these abilities cannot be optimally developed. According to Julianto et al. (2023) implementing the inquiry model in science learning can increase students' understanding of science concepts and also improve their critical thinking and metacognitive skills.

Conclusion

The conclusion that can be drawn from this study is that biology instruction using a guided inquiry model integrated with various forms of scaffolding is effective in developing students' critical thinking and metacognitive skills. Theoretically, this study contributes to the expansion of research on learning using the guided inquiry model by integrating various forms of scaffolding to help bridge the achievement gap among students. However, further research is needed to develop this into a learning model that is easy to implement, in order to determine the model's effectiveness regarding other thinking skills.

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Conceptualization, A. D, Y. G, L. L; methodology, Y. G, L. L; creating lesson plan and research instrument, A. D; validation, Y. G, L. L; investigation, A. D, Y. G, L. L; resources, A. D, Y. G, L. L; data curation, A. D, Y. G; writing original draft preparation, A. D, Y. G; writing review and editing, A. D, Y. G, L. L; project administration, Y. G, L. L. All authors have read and approved the published version of the manuscript.

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The authors declare have not conflict of interest associated with the publication of this paper.

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