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The Effect of Implementing Formative Assessment with the 5E Learning Cycle Model on High School Students' Scientific Reasoning Abilities

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A B S T R A C T

Students' scientific reasoning abilities remain relatively low, often due to limited interactive learning and insufficient feedback during instruction. This study investigates the effect of implementing formative assessment within the 5E Learning Cycle model to enhance these abilities. A quantitative approach was employed using a pre-experimental one-group pretest–posttest design. The sample consisted of 35 eleventh-grade students from a public high school in Bandung, selected through purposive sampling. Research instruments included a scientific reasoning ability test and formative assessment sheets. The findings reveal a significant improvement in students' scientific reasoning after the intervention. Results from the paired sample t-test indicate a statistically significant difference between pretest and posttest scores ($p < 0.05$), with an effect size of 4.64, categorized as very large. Additionally, students' average formative assessment scores increased from 67.42 in the first meeting to 80.12 in the second meeting. These results suggest that integrating formative assessment into the 5E Learning Cycle model provides meaningful feedback and promotes active engagement, leading to substantial improvements in scientific reasoning. Therefore, this approach can be considered an effective strategy to support higher-order thinking skills in science learning.

1. Introduction

Biology learning should not merely emphasize the mastery of factual knowledge but also prioritize the development of students' scientific reasoning skills. Scientific reasoning refers to a set of cognitive abilities that include formulating problems, proposing hypotheses, designing experiments, analyzing data, and drawing conclusions based on empirical evidence (Lawson, 2000). In the context of the 21st century, these skills are increasingly essential as individuals are required to think critically, solve complex problems, and make decisions grounded in data. Scientific reasoning enables students not only to understand natural phenomena but also to apply scientific concepts meaningfully in everyday life. As highlighted by Zimmerman (2007), scientific reasoning forms the basis of scientific literacy, empowering individuals to actively and critically participate in a society shaped by rapid scientific and technological advancements. Therefore, biology education must move beyond content delivery toward fostering scientific thinking.

A growing body of research indicates that scientific reasoning is closely linked to improved learning outcomes. Students who are capable of analyzing evidence, constructing logical arguments, and drawing reasoned conclusions tend to develop a deeper understanding of concepts and retain knowledge more effectively. Moreover, scientific reasoning supports independent learning and enhances problem-solving abilities, which are critical across academic disciplines. Empirical studies have consistently shown that students with strong reasoning skills perform better academically and demonstrate greater conceptual understanding compared to those with weaker reasoning abilities (Jeong et al., 2014; Marusic et al., 2012; Moore & Rubbo, 2012; Nieminen et al., 2012; Steinberg & Cormier, 2013; Stephans & Clement, 2010).

Despite its importance, current classroom practices often fall short in developing these skills. Assessment methods in schools are predominantly summative, focusing on final outcomes rather than the learning process. Such practices limit teachers' ability to understand how students think, identify misconceptions, or monitor conceptual development during instruction. In addition, many assessment tasks emphasize lower-order cognitive skills, such as memorizing definitions or recalling information, rather than engaging students in higher-order thinking activities like analyzing data, interpreting evidence, or constructing scientific arguments (L. P. Putri & Pujiawati, 2025; Rustaman, 2016). As a result, students have limited opportunities to practice and develop scientific reasoning.

This issue is further reflected in international assessments. The Programme for International Student Assessment (PISA) reports consistently show that Indonesian students' scientific literacy remains relatively low, particularly in reasoning and the application of knowledge in unfamiliar contexts (OECD, 2022). Data from PISA 2018 indicate that most students are only able to solve tasks requiring basic recognition of facts, while struggling with problems that demand deeper reasoning, conceptual connections, and real-world application (OECD, 2019). These findings highlight a clear gap between educational goals and classroom practices, particularly in fostering higher-order thinking skills.

To address this challenge, there is a need to shift toward assessment approaches that support learning rather than merely evaluate it. Formative assessment plays a crucial role in this regard. Unlike summative assessment, formative assessment is conducted during the learning process to monitor student progress and provide immediate feedback (Black, 1993). This feedback helps students identify their strengths and weaknesses while enabling teachers to adjust instruction accordingly (Sadler, 1989; Shepard, 2003). Although formative assessment has been widely recognized for its potential to improve learning outcomes, empirical evidence linking specific formative strategies to enhanced scientific reasoning remains limited (Black & Wiliam, 1998).

One promising approach to fostering scientific reasoning is the 5E Learning Cycle model, which consists of five stages: Engage, Explore, Explain, Elaborate, and Evaluate. This model emphasizes active student involvement in inquiry-based learning and supports the construction of knowledge through meaningful experiences. Each phase contributes to building understanding in a structured and sequential manner, encouraging students to explore concepts, develop explanations, and apply their knowledge in various contexts (Rosiana et al., 2023; Ruiz & Bybee, 2022). However, the effectiveness of this model is highly dependent on how learning is assessed throughout the process.

Integrating formative assessment into each phase of the 5E Learning Cycle offers a strategic way to enhance both learning and assessment. Through continuous feedback, students can reflect on their thinking, refine their understanding, and progressively develop their reasoning skills. At the same time, teachers gain valuable insights into students' cognitive processes, allowing for more responsive and adaptive instruction (Pellegrino, 2014; A. I. Putri et al., 2025). Despite its potential, the integration of formative assessment within the 5E framework particularly for measuring scientific reasoning remains underexplored.

Previous studies have examined the effectiveness of the 5E Learning Cycle in improving learning outcomes and scientific literacy. For instance, Wulandari et al. (2024) demonstrated that the model, when combined with multidimensional thinking worksheets, can enhance students' reasoning abilities. Similarly, Faiqoh (2024) found improvements in students' scientific explanation skills, while Djadir et al. (2021) highlighted increased learning engagement in online settings. However, these studies did not specifically focus on the role of formative assessment in systematically developing scientific reasoning. This indicates a significant research gap that needs to be addressed.

Based on this background, the present study aims to implement formative assessment within the 5E Learning Cycle model to measure and improve high school students' scientific reasoning abilities. By embedding assessment in each stage—Engage, Explore, Explain, Elaborate, and Evaluate—students receive continuous and meaningful feedback that supports their learning process. This approach is expected to create a more reflective, student-centered learning environment that promotes deeper conceptual understanding, critical thinking, and the development of scientific reasoning skills. Ultimately, this study seeks to contribute to the advancement of biology education by providing an innovative assessment strategy aligned with the demands of 21st-century learning.

2. Methodology

The type of research conducted was quantitative descriptive with a pre-experimental design, aimed at describing and analyzing the impact of the implemented learning model on students' scientific reasoning skills. This approach allows the researcher to systematically collect numerical data and interpret it to identify patterns, trends, and levels of improvement. The study was carried out in one of the public senior high schools in Bandung City, involving a selected group of students as research participants. Data were collected through various instruments such as tests and observation sheets to obtain a comprehensive understanding of the learning outcomes achieved. The population of this study were students of grade XI MIPA and the sampling technique used purposive sampling with a sample size of 35 students in grade XI MIPA 5. This study used a one-group pretest and posttest design as illustrated in Figure 1 below.

Design		
O	X	*O*
Pretest	Treatment	Posttest

Figure 1. Pretest and Posttest Design As Illustrated

Figure 1 shows that the instruments used included a multiple-choice Scientific Reasoning Test that measured aspects of variable identification, proportional reasoning, probabilistic reasoning, proportional reasoning, combinatorial reasoning, and deductive hypotheses. Furthermore, a Learning Activity Observation Sheet was used to assess the implementation of the process and observe student engagement during each stage of the 5E Learning Cycle. Formative assessments were included in each phase, including prompt questions, short quizzes, reflections on scientific reasoning answers, analysis of observation results, and mini-group discussions.

Data were analyzed using the Shapiro–Wilk normality test. Because the data were normally distributed ($p > 0.05$), differences in pretest–posttest scores were analyzed using a Paired Sample t-test. In addition to statistical significance, the magnitude of the treatment effect was calculated using effect size Cohen to determine the strength of the learning intervention's effect on students' scientific reasoning. Formative assessments were administered throughout the learning process using the 5E inquiry model. This was done to determine differences in formative assessment scores applied at each meeting. For formative assessment, the formula used is (Achieved Score / Maximum Score) × 100, for the average assessment, the value applied is the result of completing the questions in the LKPD.

3. Results and Discussion

After conducting research using pretest and posttest measurements on Grade XI MIPA 5 students, the results indicated a noticeable improvement in the average scores. This increase reflects the effectiveness of the implemented learning model or intervention, as students demonstrated better understanding and mastery of the material after the treatment. The comparison between the pretest and posttest results shows that most students experienced positive learning gains, suggesting that the instructional approach used in the study contributed significantly to enhancing students' academic performance. The difference in average scores indicates an increase in ability after the implementation of formative assessment in learning with the Learning Cycle 5E model. The average scores can be seen in Figure 2 below.

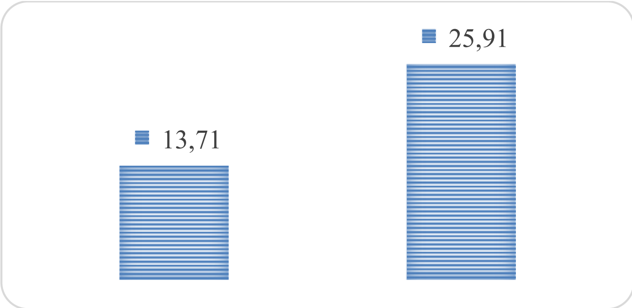

Figure 2. Average Pretest and Posttest Scores

To ensure the feasibility of the parametric analysis, a normality test was first performed using the Shapiro–Wilk test and a homogeneity of variance test using Levene's test. The normality test was conducted to determine whether the data distribution of both the pretest and posttest scores followed a normal distribution. This step is essential because parametric statistical tests require normally distributed data to produce valid results. The Shapiro–Wilk test was selected due to its suitability for small to moderate sample sizes and its high level of accuracy. Furthermore, the homogeneity of variance test using Levene's test was applied to examine whether the variances between groups were equal. Homogeneous variance is another important assumption that must be met before conducting parametric tests such as the t-test. If the results of these prerequisite tests indicate that the data are normally distributed and homogeneous, then parametric analysis can be appropriately applied. Otherwise, non-parametric alternatives would need to be considered to ensure the validity of the findings.The results of the normality test can be seen in Table 1 below.

Table 1. Normality Test Results Values

	Shapiro-Wilk		
	Statistic	**df**	**Sig.**
Pretest Score	.952	35	.134
Posttest Score	.952	35	.135

The results of the normality test presented in Table 1 indicate that both the pretest and posttest scores were normally distributed, as evidenced by the Shapiro–Wilk significance values of 0.134 and 0.135 ($p > 0.05$), respectively. These findings confirm that the data meet the assumption of normality, which is a key requirement for conducting parametric statistical analyses. Since this assumption was satisfied, further analysis using parametric tests could be carried out with confidence. Subsequently, a hypothesis test was conducted using the Paired Sample T-Test, which is specifically designed to compare the means of two related groups. In this study, the test was applied to examine the differences between students' scores before the treatment (pretest) and after the treatment (posttest). The use of this test allows for a more accurate evaluation of the effectiveness of the implemented learning intervention. By comparing the two sets of scores, it becomes possible to determine whether there is a statistically significant improvement in students' performance. The results of the Paired Sample T-Test therefore provide important evidence regarding the impact of the treatment on students' learning outcomes. The results of the statistical analysis are shown in Table 2 below.

Table 2. T-Test Result Values

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pretest Score – Posttest Score	-12.229	2.636	.445	-13.134	-11.323	-27.450	34	.000

The results of the Paired Sample t-Test in Table 2 show a significant difference between pretest and posttest scores (t = -27.450; p = 0.000), with an average difference of -12.229. This indicates that after implementing formative assessment in the 5E model, there was a very significant increase in students' scientific reasoning abilities. To determine the magnitude of the impact of formative assessment implementation on students' scientific reasoning abilities in practice, an effect size calculation was performed using Cohen d for a paired design with the formula:

$$d = \frac{t}{\sqrt{n}}$$

Effect size provides information about the practical significance of the differences found, so that researchers can determine whether the learning intervention has a substantial impact, not just statistically significant (Cohen, 1988), With the results of the t value = -27.450 and the number of samples n = 35, the effect size results were obtained at -4.64, because the absolute Cohen value was 4.64, it is included in the very large effect category based on Cohen interpretation criteria (0.20 = small; 0.50 = medium; 0.80 = large; >1.0 = very large). This effect size value shows that the application of formative assessment in the Learning Cycle 5E model has a very strong and substantive influence on improving students' scientific reasoning abilities. Formative assessment is not only effective as an evaluation tool, but also functions as a pedagogical intervention that can have a real impact on the quality of students' understanding and scientific reasoning abilities.

After measuring the effect size, other data obtained from the first formative assessment session yielded an average student score of 67.42, with a lowest score of 50 and a highest score of 86. In the second formative assessment session, the average student score was 80.12, with a lowest score of 67.12 and a highest score of 92.18. This increase in scores indicates a development in students' scientific understanding and reasoning skills after participating in a series of learning activities. To understand the factors contributing to this improvement, it is necessary to analyze how the learning process using the 5E Learning Cycle model provides a more meaningful, structured, and systematic learning experience for students.

The lesson began with the Engage phase, which aimed to arouse students' curiosity through the screening of a 3D video about the digestive process. This video presented real-life phenomena, capturing their attention and activating their prior knowledge. After watching, students were asked probing questions and directed to write down their curiosity and then organize them into a scientific question. Based on these questions, students formulated an initial hypothesis describing their predictions about the observed phenomenon. At this stage, scientific reasoning reflection is given to help students recognize the development of their thinking, especially regarding how curiosity can develop into questions and hypotheses.

In the Explore stage, students explore the scientific questions and hypotheses through group discussions, prior knowledge acquisition, and relevant additional observations. This stage provides space for students to construct initial understanding independently without teacher intervention. Scientific reasoning reflection at this stage aims to enable students to assess the clarity of their questions, the logic of their hypotheses, and the need for additional information before moving on to the next stage. In the Explain stage, students convey their curiosity, explain their hypotheses, and discuss the scientific reasoning behind these assumptions. The teacher then corrects any inaccurate concepts and enriches students' understanding through appropriate scientific explanations. In this stage, scientific reasoning reflection helps students evaluate the accuracy of their arguments and readjust their understanding based on the explanations obtained.

The Elaborate stage provides students with the opportunity to apply their conceptual understanding more deeply through analyzing provided data, specifically data on the relationship between nutrient content and the digestive process. In this stage, students connect learned concepts with empirical evidence, encouraging them to use scientific reasoning in a more complex manner. Scientific reasoning reflection at this stage helps students recognize the strengths and weaknesses of their analysis, as well as their ability to relate data to biological concepts. In the Evaluate stage, students present the results of their data analysis and then compare them with those of other groups to assess appropriateness, discrepancies, and potential errors in interpretation. Students are also guided to examine areas of deficiencies and identify improvement strategies. Scientific reasoning reflection at this stage serves to practice self-evaluation skills, assess the quality of data interpretation, and strengthen the ability to make evidence-based decisions.

The results of this study align with the findings of Shepard (2003) who found that simulation-based inquiry learning combined with formal formative assessment facilitated conceptual change in students. Students shifted from alternative ideas to correct scientific concepts after receiving continuous feedback throughout the learning process. These findings support the working mechanism of formative assessment in the 5E Learning Cycle model used in this study. With formative assessment as an integral part of each stage engage, explore, explain, elaborate, and evaluate students were given the opportunity to explore concepts, test conjectures through hypotheses and data analysis, and reflect on their scientific reasoning. This process allowed for the emergence of cognitive conflict, revision of understanding, and the accumulation of more correct scientific concepts. The significant increase in scientific reasoning scores in this study can be understood not simply as a result of practice or repetition, but as a result of an effective process of scientific inquiry and reflection, providing empirical evidence that formative assessment within an inquiry context truly deepens students' conceptual understanding.

Furthermore, this research is consistent with other research findings showing that the implementation of the 5E Learning Cycle has a positive impact on students' scientific reasoning skills, particularly when supported by the use of worksheets and a multimodal learning approach that encourages active student engagement in each learning stage (Dewi et al., 2024; Ristia et al., 2024). This approach allows students to gradually build conceptual understanding through structured exploration, elaboration, and evaluation activities, allowing for optimal scientific thinking development. The interaction between the 5E model and formative assessment also strengthens the development of students' scientific thinking skills by providing continuous feedback throughout the learning process. Formative assessment, integrated into each learning phase, plays a crucial role in helping students reflect on their understanding, correct conceptual errors, and continuously improve the quality of scientific reasoning. The 5E Learning Cycle model requires students to actively think, explore, and prove, all while still being guided by the teacher, so that the knowledge gained is more deeply embedded and more memorable (Agusti, 2023; Pra Dita et al., 2021). The implementation of formative assessment also gives students time to explore and obtain a number of facts, concepts, and principles so that learning becomes more meaningful.

4. Conclusion

The results of this study indicate that the application of formative assessment with the 5E Learning Cycle model significantly improves students' scientific reasoning skills in biology learning. This improvement is evidenced by the increase in students' average scores from pretest to posttest and is statistically supported by highly significant paired sample t-test results and a very large effect size, indicating a strong positive impact of formative assessment. The novelty of this study lies in the integration of formative assessment at each phase of the 5E Learning Cycle, which consistently engages students in reflective thinking and supports the gradual development of scientific reasoning. Furthermore, the progressive increase in formative assessment scores across learning sessions indicates that continuous feedback improves students' conceptual understanding and the quality of scientific responses. Therefore, formative assessment is recommended as an integral component of the 5E Learning Cycle to strengthen scientific reasoning, and future research can explore its application across different topics or educational levels.

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