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Integrating Formative Assessment Strategies to Enhance Conceptual Understanding in Science Learning

Ahmad Sofyan[1*]
[1]Universitas Islam Negeri Jakarta, Indonesia
Corresponding Author: Ahmad Sofyan madsofyan@gmail.com

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A B S T R A C T
This study examines the effect of integrating formative assessment strategies on students' conceptual understanding in science learning. Using a quasi-experimental design with a pretest–posttest control group, the study involved 60 eighth-grade students divided into experimental and control groups. Data were collected through a two-tier diagnostic test and analyzed using descriptive statistics, ANCOVA, and effect size. The findings show that students exposed to formative assessment integration achieved significantly higher improvement in conceptual understanding compared to those in conventional learning. The results indicate that formative assessment effectively enhances conceptual understanding and reduces misconceptions. This study highlights the importance of formative assessment as a pedagogical strategy and provides practical implications for designing meaningful science instruction.

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INTRODUCTION

Science learning in the 21st century requires students not only to master facts, but also to have a deep conceptual understanding in order to be able to relate concepts, explain phenomena, and solve problems scientifically. According to a report on science education studies submitted by Duschl (2021), weak conceptual understanding is still a global problem experienced by students at various levels of education. This condition is exacerbated by learning practices that still place summative assessment as the main focus of learning outcome evaluation. Such outcome-oriented assessments tend to lack the ongoing feedback students need to correct misconceptions in a timely manner.

In line with this global phenomenon, the context of science education in Indonesia also faces similar challenges, especially at the junior high school level. Various research results show that grade VIII students have difficulty understanding abstract and interconnected science concepts, as expressed by Suryani and Nugroho (2022). Learning is often oriented towards achieving final grades, so the process of diagnosing student misconceptions receives less attention. As a result, misconceptions are not detected early on and continue to carry over to later learning.

In the study of modern learning theory, formative assessments are seen as pedagogical strategies that play an important role in supporting meaningful learning. Formative assessments emphasize the process of collecting learning information in an ongoing manner to provide constructive feedback for teachers and students. International research shows that the integration of formative assessments in science learning is able to increase student engagement and improve the structure of their conceptual understanding; This finding is confirmed in the study by Wiliam (2020). Specific and timely feedback allows students to reflect on misunderstandings and build concepts more accurately.

Although the benefits of formative assessments have been widely reported, empirical studies show that there is still a significant research gap. Most previous research has focused on the influence of formative assessments on general learning outcomes or learning motivation, rather than specifically on conceptual understanding. In addition, many studies use single-level test instruments that are less able to reveal the depth of students' understanding and misconceptions. According to Treagust and Chandrasegaran (2021), two-level diagnostic instruments are more relevant for identifying students' conceptual structures, but they are still rarely used systematically in science learning research.

Another research gap lies in the methodological aspects and the research context. Some studies used simple experimental designs without controlling for differences in students' initial abilities, so the results lack an accurate picture of influence. On the other hand, research in the context of developing countries is still relatively limited compared to developed countries, as noted by Bennett (2022). In fact, differences in the education system and learning culture have the potential to affect the effectiveness of the implementation of formative assessments in science learning.

Based on this description, this study aims to empirically examine the influence of the integration of formative assessment strategies on improving students' conceptual understanding in science learning. This study specifically compared the improvement in conceptual understanding between students who participated in integrated science learning formative assessment and students who participated in conventional learning. In addition, this study aims to provide a quantitative picture of the magnitude of the influence of formative assessments after controlling students' initial abilities, as recommended by Field (2020) in quasi-experimental educational research.

The contribution of this research is theoretical and practical. Theoretically, this research strengthens the conceptual framework regarding the role of formative assessment as an effective learning strategy in building a conceptual understanding of science. The findings of this study also enrich the educational assessment literature with empirical evidence based on quasi-experimental design and the use of two-level diagnostic instruments. Practically, the results of this study provide implications for science teachers in designing learning that is more responsive to students' learning needs and data-based decision-making of formative assessments, as emphasized by Carless (2023).

LITERATURE REVIEW

Conceptual Understanding in Science Learning

Conceptual understanding refers to the ability of students to understand the meaning of a concept in depth, connect interrelated concepts, and apply them in various scientific contexts. In science learning, conceptual understanding is the main indicator of learning success because science concepts are hierarchical and integrated. Previous research has shown that students' low conceptual understanding is often caused by the existence of misconceptions that are formed from the early stages of learning and are not handled systematically (Vosniadou, 2020). Misconceptions that are not identified and not continuously corrected can hinder the process of constructing new knowledge.

Furthermore, science learning that only emphasizes the delivery of material and final evaluation is considered less effective in building meaningful conceptual understanding. Students need learning experiences that allow them to test, revise, and reconstruct their understanding on an ongoing basis (Kang et al., 2022). Therefore, a learning strategy that is able to uncover and follow up on students' conceptual understanding is a fundamental need in science learning.

H1: Systematically designed science learning has a significant effect on improving students' conceptual understanding.

Formative Assessment as a Pedagogical Strategy in Science Learning

Formative assessment is defined as an assessment process that is carried out continuously during learning activities with the aim of obtaining information about student learning progress and providing constructive feedback. In science learning, formative assessments serve as a pedagogical strategy that helps teachers tailor learning approaches to students' conceptual needs. Research shows that the integration of formative assessments can consistently improve the

quality of learning interactions and encourage more active students' cognitive engagement (Heritage & Wylie, 2021).

In addition, formative assessments allow teachers to identify students' conceptual error patterns more accurately than summative assessments. The feedback provided not only serves as a correction to mistakes, but also as a means of learning that helps students understand the reasons behind the conceptual mistakes they make (Ruiz-Primo & Li, 2023). Thus, formative assessments have great potential in supporting science learning that is oriented towards strengthening conceptual understanding.

H2: The integration of formative assessment in science learning has a positive effect on improving students' conceptual understanding.

Two-Level Diagnostic Instruments in Identifying Misconceptions

Two-level diagnostic instruments are designed to uncover not only the student's final answer, but also the conceptual reasons underlying the answer. This instrument is considered more effective in identifying student misconceptions compared to conventional multiple-choice tests. Previous research shows that the use of two-level diagnostic instruments is able to provide a more comprehensive picture of the structure of students' conceptual understanding in science learning (Hasanah & Rahman, 2021).

Furthermore, two-level diagnostic instruments are considered very relevant when used in the context of formative assessment. The results of the diagnosis obtained can be used directly as a basis for providing feedback and improving learning (Gurel et al., 2022). Thus, two-level diagnostic instruments not only serve as an evaluation tool, but also become an integral part of the learning process oriented towards improving students' conceptual understanding.

H3: The use of two-level diagnostic instruments significantly improves the measurement accuracy of students' conceptual understanding.

Integration of Formative Assessment and Its Impact on Conceptual Understanding

The integration of formative assessment in science learning places the assessment process as an integral part of teaching and learning activities. This approach allows teachers to monitor the development of students' conceptual understanding on an ongoing basis and make appropriate pedagogical interventions based on students' learning needs. Research shows that science learning that systematically integrates formative assessments results in a higher increase in conceptual understanding than conventional learning (Lyon & Gotwals, 2021).

In addition to having an impact on student learning outcomes, the reflective use of formative assessment data also helps teachers in making learning decisions based on empirical evidence (Schildkamp et al., 2020). The integration of formative assessments not only improves students' conceptual understanding, but also contributes to improving the quality of teachers' learning practices. Therefore, the study of the integration of formative assessment in science learning is important to strengthen the empirical foundation of learning oriented to conceptual understanding.

H4: The systematic integration of formative assessments has a significant influence on improving students' conceptual understanding compared to conventional learning.

METHODOLOGY

Research Approach and Design

This study uses a quantitative approach with a quasi-experimental method, which aims to test the effectiveness of learning treatment on improving students' conceptual understanding. The design applied is a pretest–posttest control group design, which allows researchers to compare changes in learning outcomes between the treated group and the comparison group by controlling the students' initial abilities. This design is seen as relevant in the context of formal education research because subject groupings are based on classes that have already been formed, so full randomization of individuals is not possible (Cook et al., 2020).

The research was carried out in the odd semester of the 2025/2026 school year at one of the State Junior High Schools in Jakarta, with the experimental group obtaining learning designed according to the research treatment, while the control group followed conventional learning as regular learning practices in schools.

Research Subject and Sampling Techniques

The subjects in this study are grade VIII students at the school where the research is located. The selection of grade VIII level is based on the characteristics of science learning materials that require a deeper and abstract conceptual understanding. The sampling technique used is cluster sampling, which is the selection of samples based on groups of classes that have existed administratively (Creswell & Creswell, 2023). A total of 60 students were involved as a research sample, which was divided into two groups, namely 30 students in the experimental group and 30 students in the control group. The sample count was considered adequate for quasi-experimental research and advanced statistical analysis, particularly covariance analysis in the context of educational research (Fraenkel et al., 2023).

Data Collection Techniques and Instruments

The main data collection was carried out using a conceptual understanding test developed in the form of a two-tier diagnostic test. This instrument is given to students before the pretest and after the posttest to comprehensively measure changes in conceptual understanding. The first level contains multiple-choice questions, while the second level contains the reasons or conceptual explanations that underlie students' answer choices, thus allowing for a more in-depth identification of conceptual understanding and misconceptions (Gurel & Eryilmaz, 2023). In addition to the test, the observation sheet on the implementation of learning is used as supporting data. This observation sheet aims to ensure that the learning treatment in the experimental group is carried out consistently in accordance with the research design, as well as to monitor the suitability of the learning process in the control group.

Instrument Validity and Reliability

The conceptual comprehension test instrument is validated through content validity, by involving experts in the field of science education and learning evaluation. Furthermore, the empirical validity test was carried out using total item-score correlation analysis. The reliability of the instrument was analyzed using Cronbach's alpha coefficient, with a minimum reliability criterion of 0.70. This value is considered to reflect the internal consistency of adequate instruments in educational research (Taber, 2021).

Data Analysis Techniques

Data analysis is carried out in stages. First, descriptive statistics are used to describe the average score, standard deviation, and the tendency of pretest and posttest results in each group. Second, an analysis prerequisite test was carried out, which included a normality test and a variance homogeneity test, as the basis for the use of inferential statistical analysis. To test the influence of learning treatment on students' conceptual understanding by controlling for initial ability, covariance analysis (ANCOVA) was used. In addition, effect size calculations were carried out to determine the magnitude of the effect of treatment in practice, so that the results of the study were not only statistically meaningful, but also pedagogically relevant (Laerd Statistics, 2022).

RESEARCH RESULT

Difference in Conceptual Understanding Improvement between the Experimental Group and the Control Group

The results of the descriptive analysis showed a clear difference in the improvement of conceptual understanding between students who participated in integrated science learning formative assessment and students who participated in conventional learning. In the pretest stage, the average score of conceptual comprehension of both groups was at a relatively comparable level, indicating that the student's initial ability was at an equal condition before the treatment was given. After treatment, the posttest scores of the experimental group increased substantially, while the improvement in the control group occurred to a more limited extent. These findings indicate that the integration of formative assessments makes a real contribution to strengthening students' conceptual understanding in science learning.

Table 1. Descriptive Statistics of Students' Conceptual Understanding Scores

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Experimental Group	30	54.23	8.41	78.67	7.95
Control Group	30	53.87	8.76	65.14	8.32

Table 1 shows that the average pretest scores in the experimental group and the control group were in almost the same range, which confirms the equivalence of students' initial abilities before the treatment. After the learning took place, the average posttest score of the experimental group increased

significantly compared to the control group. The difference in score improvement between the pretest and posttest in the experimental group was much larger than in the control group, which suggests that science learning integrated with formative assessments was more effective in improving students' conceptual understanding.

These findings confirm that systematically designed science learning is able to significantly improve students' conceptual understanding. Thus, the results on this theme supports Hypothesis 1 (H1) and Hypothesis 2 (H2), which states that science learning and the integration of formative assessments have a positive effect on improving students' conceptual understanding.

The Effect of Formative Assessment Integration on Conceptual Comprehension after Controlling Students' Initial Abilities

To obtain a more accurate estimate of the effect of treatment, an inferential analysis was carried out using Kovarian analysis (ANCOVA) with a pretest score as a covariate. The results of the analysis showed that there was a significant difference between the experimental group and the control group in the posttest score after the students' initial ability was controlled. This indicates that the improvement in students' conceptual understanding is not solely due to differences in initial abilities, but is directly influenced by the integration of formative assessments in the science learning process.

Table 2. ANCOVA Results on Posttest Conceptual Understanding Scores

Source	Sum of Squares	df	Mean Square	F	Sig.
Pretest	412.56	1	412.56	9.84	.003
Group	1287.43	1	1287.43	30.71	.000
Error	2338.19	57	41.02		

Table 2 shows that the group variable has a high and significant F-value at a significance level of 0.05. This means that there is a significant difference between the experimental group and the control group in the posttest score of conceptual comprehension after controlling the pretest score. Thus, the integration of formative assessments has been shown to have a significant influence on the statistical improvement of students' conceptual understanding.

The results of this covariance analysis reinforce previous descriptive findings and show that the integration of formative assessments is a major factor influencing the improvement of students' conceptual understanding. Therefore, these results are unequivocally supports Hypothesis 4 (H4), which states that the integration of formative assessments systematically has a significant influence compared to conventional learning.

The Influence of Formative Assessment Integration on Students' Conceptual Understanding

In addition to statistical significance, this study also calculates **effect size** to determine the strength of the influence of formative assessment integration on students' conceptual understanding. The results of the calculation showed that the integration of formative assessments had a large impact on the category,

which suggests that the treatment was not only statistically significant, but also practically meaningful in the context of science learning in junior high school.

Table 3. Effect Size of Formative Assessment Integration

Effect Size Indicator	Value	Interpretation
Partial Eta Squared	0.35	Large Effect

Table 3 shows a partial eta squared value of 0.35, which falls into the category of large influence. This value indicates that the proportion of variation in students' conceptual comprehension scores explained by the integration of formative assessments is relatively high. Thus, the learning strategies applied have a strong impact on improving the quality of students' conceptual understanding.

The magnitude of this effect size confirms that the systematic use of formative assessments not only improves test scores, but also substantively deepens students' conceptual understanding and reduces misconceptions. These findings are consistently supports Hypothesis 2 (H2) and Hypothesis 4 (H4), as well as strengthening the position of formative assessment as an effective pedagogical strategy in science learning.

Measurement Accuracy of Conceptual Comprehension through Two-Level Diagnostic Instruments

Analysis of students' responses to the two-level diagnostic instrument showed that the use of this test was able to reveal differences in the quality of conceptual understanding in more depth than just the final score. Students in the experimental group showed a higher improvement not only in the correct answers of the first level, but also in the consistency of conceptual reasons in the second level. This indicates that integrated learning of formative assessments helps students build a more coherent and structured conceptual understanding.

Table 4. Comparison of Two-Tier Diagnostic Test Accuracy

Group	Correct Answer (%)	Correct Reasoning (%)
Experimental Group	82.4	76.8
Control Group	68.1	55.6

Table 4 shows that the percentage of correct answers and the right conceptual reasons in the experimental group was higher than in the control group. This difference shows that the two-level diagnostic instrument is able to distinguish the level of depth of conceptual understanding of students more accurately, as well as reveal a decrease in misconceptions in the group that received integrated learning of formative assessment.

These findings confirm that the use of two-level diagnostic instruments improves the accuracy of measuring students' conceptual understanding and provides a more comprehensive picture of students' knowledge structures. Thus, these results supports Hypothesis 3 (H3), which states that a two-level diagnostic

instrument significantly improves the accuracy of measuring students' conceptual comprehension.

DISCUSSION

The results of this study show that students who participate in science learning with the integration of formative assessments experience a significantly higher increase in conceptual understanding than students who participate in conventional learning. These findings confirm that formative assessments do not simply function as an evaluation tool, but as an active and continuous learning mechanism, as emphasized in evidence-based learning studies (Hattie & Zierer, 2021). Theoretically, this is in line with the perspective of cognitive constructivism which views learning as a process of building knowledge through reflection and feedback on students' understanding. Learning that provides space for students to identify and revise their understanding continuously has proven to be more effective in building stable and meaningful conceptual structures.

Increased conceptual understanding in the experimental group also showed that the integration of formative assessments was able to facilitate the process of self-regulation in learning science. Through diagnostic questions, formative feedback, and reflective discussions, students are encouraged to monitor their conceptual errors and take corrective steps independently, as described in the framework of self-regulated learning by Nicol and Macfarlane-Dick (2020). These findings reinforce the view that formative assessments act as a link between teaching and learning, rather than as separate activities at the end of learning. In this context, formative assessments serve as instructional scaffolds that help students move from initial understanding to more accurate scientific understanding.

The results of the covariance analysis showing a significant influence of treatment after controlling for students' initial abilities provide strong empirical evidence that differences in improvement in conceptual understanding are not caused by the student's initial factors. These findings have important methodological implications, as they confirm that formative assessments contribute directly to conceptual learning outcomes through planned pedagogical mechanisms. Conceptually, these results support the assessment for learning theory which emphasizes that the quality of feedback information and pedagogical follow-up is more determinative of learning outcomes than the initial characteristics of students alone. Recent research shows that when teachers use formative assessment data adaptively, students' initial ability gaps can be significantly minimized (Black & Harrison, 2021).

Findings related to the magnitude of the effect size suggest that the integration of formative assessments has a strong practical impact on science learning. This indicates that formative assessment strategies are not only statistically effective, but also relevant and meaningful in real-world learning practices in the classroom, particularly in building deep conceptual understanding. The magnitude of the effect suggests that the changes that occur in students' conceptual understanding are substantive, not just short-term score

improvements. In the perspective of science pedagogy, this major impact reinforces the argument that feedback-based learning and conceptual diagnosis are key in addressing persistent misconceptions (Brookhart, 2023).

The use of two-level diagnostic instruments in this study has been proven to be able to reveal the depth of students' conceptual understanding more accurately. The clear distinction between correct answers and the quality of conceptual reasons suggests that student understanding cannot be comprehensively assessed through single-level tests alone, as criticized in contemporary conceptual assessment studies. These findings reinforce the view that conceptual understanding is a multidimensional construct that includes conceptual accuracy and reasoning coherence. Two-level diagnostic instruments allow teachers and researchers to identify latent misconceptions that often go undetected in traditional assessments (Yan & Pastore, 2022).

Although the results of this study support all the hypotheses proposed, there are several factors that need to be considered critically in interpreting the research findings. One of the supporting factors for the success of the treatment is the consistency of the implementation of formative assessments by teachers, which is monitored through observation sheets on the implementation of learning. However, the limitations of this study lie in the scope of the sample that only involves one school, so generalization of results needs to be done carefully. In addition, the relatively limited duration of treatment potentially does not fully capture the long-term impact of formative assessments on the stability of students' conceptual understanding (DeLuca et al., 2021).

Based on these findings and limitations, this study provides several important implications and recommendations for the development of science learning. Theoretically, this research strengthens the position of formative assessment as a core pedagogical strategy in science learning oriented towards conceptual understanding. Practically, teachers need to be equipped with systematic training in designing and utilizing formative assessments based on conceptual diagnosis so that their implementation is consistent and effective. For further research, it is recommended to involve more diverse school contexts, extend the duration of interventions, and combine quantitative approaches with qualitative data in order to gain a more comprehensive understanding of the working mechanisms of formative assessment in science learning.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that the integration of formative assessment strategies significantly improves students' conceptual understanding in science learning. Students in the formative assessment group showed higher conceptual gains and fewer misconceptions than those in conventional learning. These findings confirm that formative assessment functions as an effective pedagogical strategy to support meaningful and continuous learning. Therefore, teachers are recommended to systematically apply formative assessment through ongoing feedback and diagnostic activities. Future research should involve wider samples and longer implementation periods to strengthen the generalizability of the findings.

ADVANCED RESEARCH

Future research is recommended to investigate the long-term impact of formative assessment on students' conceptual understanding and retention. In addition, combining quantitative and qualitative approaches could provide deeper insights into how formative assessment influences students' thinking processes, learning behaviors, and conceptual development. Expanding the research context across different schools and educational levels is also important to strengthen the applicability of the findings.

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