Assessment for learning in chemistry learning: One of the best ways to improve learning outcomes

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Abstract
The integration of macroscopic, submicroscopic, and symbolic representations remains a major challenge in chemistry education, particularly when teaching abstract concepts such as electrolyte and nonelectrolyte solutions. This study aimed to investigate the implementation of the Assessment for Learning (AfL) approach and examine its effectiveness in improving students' conceptual understanding of this topic. A pre-experimental study with a one-group pretest–posttest design was conducted involving 36 eleventh-grade students from a public senior high school in Surabaya. Data were collected using a validated 12-item conceptual understanding test and analyzed using the Wilcoxon signed-rank test and N-gain analysis. The results showed a significant improvement in students' learning outcomes, with the mean score increasing from 43.26 in the pretest to 89.72 in the posttest. The Wilcoxon test produced an Asymp. Sig. (2-tailed) value of 0.000 (<0.05), indicating a statistically significant difference between the pretest and posttest scores. Furthermore, the N-gain analysis revealed that 91.67% of students achieved a high category of improvement in conceptual understanding. These findings demonstrate that the systematic implementation of AfL strategies clarifying learning objectives, facilitating productive classroom discussions supported by student activity sheets, providing continuous formative feedback, and activating students as owners of their learning effectively supports students in connecting different levels of chemical representation. This study suggests that integrating formative assessment into classroom instruction can help teachers identify and address students' misconceptions during the learning process, thereby promoting deeper conceptual understanding in chemistry education.

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1. Introduction

Science education aims not only to help students acquire scientific knowledge but also to develop their ability to analyze phenomena, construct explanations, and apply scientific reasoning in real-life contexts. Effective science learning therefore requires students to actively engage in exploring ideas, interpreting evidence, and reflecting on their understanding during the learning process (Ahmad et al., 2024). However, classroom practices in many educational contexts still tend to emphasize teacher-centered instruction, where assessment is primarily used to measure learning outcomes at the end of instruction rather than to support learning throughout the learning process (Ningtryas et al., 2025; Martins van Jaarsveld et al., 2025). As a result, students often have limited opportunities to receive meaningful feedback that can help them identify misconceptions and improve their conceptual understanding during learning activities.

Chemistry learning presents additional challenges because many chemical concepts involve abstract phenomena that cannot be directly observed. Chemical processes occur at the molecular and ionic levels, requiring students to understand interactions among atoms, ions, and molecules (John Hattie & Helen Timperley, 2007; Hu-Au, 2024). To develop meaningful conceptual understanding, students must be able to connect three levels of chemical representation: the macroscopic level that describes observable phenomena, the submicroscopic level that explains particle interactions, and the symbolic level that represents chemical processes through formulas and equations (Gkitzia et al., 2020; Popova & Jones, 2021). Difficulties in linking these representations often result in fragmented understanding and misconceptions in chemistry learning.

One chemistry topic that requires strong integration of these representations is electrolyte and nonelectrolyte solutions. In this topic, students must relate observable phenomena, such as a solution's ability to conduct electricity, to particle-level explanations involving ionization processes. At the same time, they must interpret these processes symbolically through chemical equations and calculations related to the degree of

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ionization. Previous studies have reported that many students experience difficulties distinguishing between electrolyte and nonelectrolyte solutions and explaining the relationship between ion formation and electrical conductivity (Nofinadya et al, 2024; Keiner & Graulich, 2021; Sari et al., 2024). These learning difficulties indicate the need for instructional approaches that can support students in constructing conceptual understanding throughout the learning process.

One approach that can support this process is Assessment for Learning (AfL). Assessment for Learning refers to formative assessment practices that are integrated into instruction to gather evidence of students' understanding, provide feedback, and guide improvements in learning (Black & Wiliam, 1998; Schellekens et al., 2021). Through strategies such as clarifying learning objectives, eliciting evidence of students' thinking, providing constructive feedback, and encouraging reflection, AfL enables teachers and students to continuously monitor learning progress and adjust instructional strategies accordingly (Hattie & Timperley, 2007; Nicol & Macfarlane-Dick, 2006). Previous research has shown that formative assessment practices can improve students' learning outcomes, increase engagement in learning activities, and support the development of self-regulated learning skills (Andrade & Brookhart, 2020; Volante et al., 2025).

Despite the growing attention to formative assessment in education, several gaps remain in the existing literature. Many studies on Assessment for Learning focus on general classroom practices without specifically examining its implementation in chemistry learning contexts that involve complex multirepresentational understanding (Heritage & Wylie, 2018; Westbroek et al., 2020). In addition, empirical investigations that explore how AfL strategies are operationalized within classroom learning activities and how they influence students' conceptual understanding in specific chemistry topics remain limited (Aisy & Muchlis, 2025; Syah & Muchlis, 2025). Furthermore, studies examining AfL implementation in abstract chemistry topics such as electrolyte and nonelectrolyte solutions are still scarce, even though these topics require students to integrate macroscopic, submicroscopic, and symbolic representations to avoid misconceptions (Farrell et al., 2022).

Therefore, this study aims to investigate the implementation of the Assessment for Learning approach in chemistry learning on electrolyte and nonelectrolyte solution material and to examine its effectiveness in improving students' learning outcomes. This study extends previous research by examining the direct classroom implementation of AfL supported by student activity sheets designed according to AfL principles in a chemistry topic that requires multirepresentational understanding. The findings of this study are expected to contribute to strengthening formative assessment practices in chemistry education, particularly in learning contexts that involve abstract and multirepresentational concepts.

Based on the research background described above, the research questions of this study are formulated as follows:

a. Is there a significant difference in students' learning outcomes before and after the implementation of the Assessment for Learning approach in learning electrolyte and nonelectrolyte solutions?

b. How effective is the Assessment for Learning approach in improving students' conceptual understanding of electrolyte and nonelectrolyte solutions?

These research questions guided the design and analysis of this study. By comparing students' learning outcomes before and after the implementation of the Assessment for Learning approach, the study aimed to determine whether the intervention produced a significant improvement in students' conceptual understanding of electrolyte and nonelectrolyte solutions. In addition, the study examined the effectiveness of the AfL approach in supporting students' learning processes and improving their mastery of chemistry concepts.

2. Method

2.1. Research Design

This study employed a pre-experimental research design using a one-group pretest–posttest design to examine the effectiveness of the Assessment for Learning (AfL) approach in improving students' learning outcomes on electrolyte and nonelectrolyte solutions. This design was selected because it enables researchers to measure students' conceptual understanding before and after the implementation of a learning intervention within the same group of participants (Creswell & Creswell, 2018), thereby providing a clear baseline for evaluating the impact of the treatment.

The one-group pretest–posttest design involves a single group of participants who are measured before and after the implementation of a learning intervention. In this design, the pretest is used to determine students' initial level of understanding, while the posttest is used to measure changes in learning outcomes after the treatment is applied. By comparing the results of these two measurements, researchers can evaluate the extent

to which the intervention contributes to the improvement of students' conceptual understanding. The one-group pretest–posttest research design is presented in Figure 1.

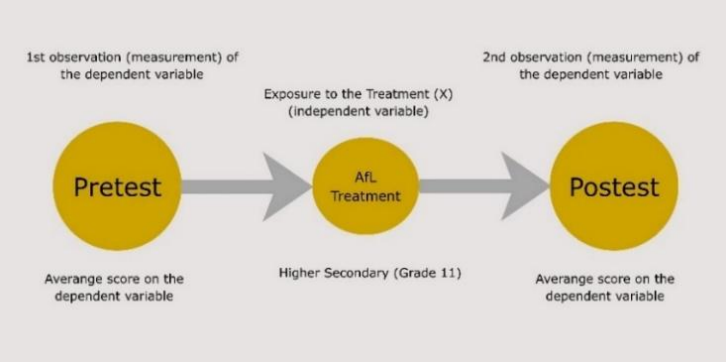


Figure 1. One-group pretest-posttest research design

As shown in Figure 1, the first observation represents the administration of the pretest, X indicates the implementation of the Assessment for Learning (AfL) approach, and the second observation represents the posttest conducted after the learning intervention.

2.2. Participants

A total of 36 eleventh-grade students from a public senior high school in Surabaya participated in this study. The participants were selected using a purposive sampling technique, in which the selected class had previously studied acid–base concepts as prerequisite knowledge for learning electrolyte and nonelectrolyte solutions. Prior to the research implementation, permission was obtained from school principals, and ethical approval was secured. All participants were informed about the purpose of the study and voluntarily agreed to participate.

2.3. Implementation of Assessment for Learning

The learning intervention in this study was conducted using the Assessment for Learning (AfL) approach, which integrates formative assessment practices into the instructional process. AfL emphasizes the use of assessment as a pedagogical strategy to monitor students' learning progress, provide feedback, and guide improvements during the learning process (Black & Wiliam, 1998; Nicol & Macfarlane-Dick, 2006). Through continuous feedback and interactive learning activities, AfL allows teachers and students to identify misconceptions and adjust learning strategies during instruction rather than evaluating learning outcomes only at the end of the lesson.

In this study, the implementation of AfL was applied to the topic of electrolyte and nonelectrolyte solutions through classroom discussions, guided learning tasks, and formative feedback provided during the learning process. Learning activities were designed to encourage students to explore observable phenomena related to electrical conductivity, analyze particle-level explanations involving ion formation, and interpret symbolic representations such as chemical equations and ionization processes. The stages of Assessment for Learning (AfL) implementation in chemistry learning are presented in Figure 2.



Figure 2. Stages of Assessment for Learning Implementation in Chemistry Learning

As shown in Figure 2, the implementation of the Assessment for Learning (AfL) approach in this study consisted of four interconnected stages (Amanina & Muchlis, 2023). In the first stage, which focuses on clarifying the learning objectives and success criteria, students were informed about the learning objectives related to the concept of electrolyte and nonelectrolyte solutions. Students were then asked to identify and write down the learning targets they expected to achieve during the lesson (Marzano, 2006). At this stage, the teacher emphasized that students should be able to explain electrolyte concepts through three levels of chemical representation: macroscopic phenomena, submicroscopic particle interactions, and symbolic chemical equations. In the second stage, which aims to elicit evidence of students' understanding, students were asked to complete learning tasks designed to reveal their conceptual understanding. These tasks encouraged students to analyze observable phenomena of electrical conductivity in solutions (macroscopic level), explain the dissociation of substances into ions in aqueous solutions (submicroscopic level), and represent these processes using chemical equations and symbols (symbolic level). During this stage, students actively participated in classroom discussions, shared their ideas, and responded to questions posed by the teacher or their peers (McKee, 2015). In the third stage, which involves engaging students as learning resources for one another and providing feedback that promotes deeper understanding, student representatives presented the results of their group discussions in front of the class (McMillan, 2024). Other students were encouraged to respond to the presenters' explanations and provide alternative ideas. At this stage, the teacher provided feedback to reinforce correct reasoning and clarify misconceptions related to electrolyte concepts across the three levels of chemical representation. Feedback was not limited to this stage but was provided continuously throughout the learning process. In the fourth stage, which focuses on activating students as owners of their learning, students conducted self-assessment through reflection questions provided by the teacher (Pat-El et al., 2024). These reflection activities encouraged students to evaluate their understanding of electrolyte and nonelectrolyte solutions and identify areas that still required improvement. Through this reflective process, students became more aware of their learning progress and received feedback that helped them recognize their strengths and weaknesses in understanding the concept.

The learning activities were supported by student activity sheets (LAPD) designed to facilitate discussion, problem-solving, and reflection activities during the implementation of the AfL approach. The worksheets functioned as learning support tools that helped students record observations, analyze experimental results, and respond to reflection questions. However, the worksheets were not the main focus of the study but were used only to support the formative assessment process during classroom learning.

2.4. Instrument Development

The instrument used in this study was a learning outcome test consisting of 12 multiple-choice questions specifically designed to measure students' conceptual understanding of electrolyte and nonelectrolyte solutions. This instrument was administered as both a pretest and posttest to examine students' mastery of the material before and after the implementation of the Assessment for Learning (AfL) approach (Lewkowicz & Leung, 2021). By using the same set of validated questions for both tests, the researchers could accurately track the shift in students' understanding and identify the specific impact of the formative intervention. The test items were developed based on learning indicators derived from the national chemistry curriculum, ensuring they appropriately covered the essential concepts of electrolyte and nonelectrolyte solutions. Each item was strategically constructed to assess higher-order thinking skills, including the ability to analyze experimental phenomena, interpret submicroscopic chemical concepts, and apply calculations related to ion concentration and conductivity. To ensure its quality, the instrument underwent a rigorous content validity process by expert judges and a reliability check before being deployed in the field.

Specifically, the test items were designed based on four indicators of conceptual understanding, namely:

a. Analyzing the properties of electrolyte and nonelectrolyte solutions based on electrical conductivity experiments.

b. Analyzing electrolyte phenomena in everyday contexts.

c. Determining the properties of solutions based on the degree of ionization.

d. Calculating and interpreting the degree of ionization of solutions.

The questions were designed to measure several cognitive levels based on the revised Bloom's taxonomy, including applying (C3), analyzing (C4), and evaluating (C5) (Anderson & Krathwohl, 2001).

2.5. Validation Procedures

Prior to its administration, the research instrument underwent a validation process to ensure that it accurately measured students' conceptual understanding of electrolyte and nonelectrolyte solutions. The

content validity of the instrument was evaluated through expert judgment, involving three experts in chemistry education. This procedure was conducted to ensure that each test item appropriately represented the intended learning indicators and aligned with the conceptual scope of the material. The validators evaluated each test item based on several criteria, including the alignment between the test items and the learning indicators, the accuracy of chemical concepts, the clarity of language, and the suitability of the difficulty level for senior high school students. The evaluation was conducted using a four-point Likert scale, consisting of 1 (not valid), 2 (less valid), 3 (valid), and 4 (very valid). Higher scores indicated a greater level of relevance and appropriateness of the test items in representing the intended learning objectives.

he validity of each item was determined based on the median score obtained from the experts' evaluations. Test items with a median score of ≥ 3 were considered valid and appropriate for use in the research instrument, while items with lower scores were revised based on the feedback and suggestions provided by the validators. Through this validation process, the instrument was ensured to adequately represent the key concepts of electrolyte and nonelectrolyte solutions and to measure students' conceptual understanding across the macroscopic, submicroscopic, and symbolic levels of chemical representation.

2.6. Reliability Testing

The reliability of the research instrument was analyzed to determine the internal consistency of the test items in measuring students' conceptual understanding of electrolyte and nonelectrolyte solutions. Reliability analysis was conducted using the Cronbach's Alpha coefficient with the assistance of SPSS software version 23. Cronbach's Alpha is widely used in educational research to evaluate the extent to which a set of test items consistently measures the same construct. A higher Cronbach's Alpha value indicates stronger internal consistency among the items in the instrument.

In this study, the reliability coefficient was interpreted based on commonly accepted criteria in educational measurement. An Alpha value of 0.70 or higher indicates acceptable reliability, while values above 0.80 indicate a high level of internal consistency (Tavakol & Dennick, 2011). The reliability analysis was conducted after the validation process to ensure that the instrument used in the pretest and posttest provided consistent and dependable measurement results.

2.7. Data Analysis

The data obtained from the pretest and posttest were analyzed to determine whether the implementation of the Assessment for Learning approach improved students' learning outcomes on electrolyte and nonelectrolyte solution material. First, the pretest and posttest data were subjected to a normality test to determine the distribution characteristics of the data. Since the sample size was fewer than 50 participants, the Shapiro–Wilk test was used to assess normality using SPSS software version 23 (Nardi, 2018). This test is considered more appropriate and sensitive for small sample sizes. The decision for the normality test was based on the significance value (Sig.). If the Sig. value was greater than 0.05, the data were considered normally distributed. Conversely, if the Sig. value was less than or equal to 0.05, the data were considered not normally distributed (Muhson, 2016).

To determine whether there was a difference between the pretest and posttest scores, a mean difference test was then conducted. If the data were normally distributed, a parametric statistical test, namely the paired sample t-test, was used. However, if the data did not meet the normality assumption, a non-parametric statistical test, the Wilcoxon signed-rank test, was applied. The mean difference analysis was performed using SPSS software version 23. The decision-making process was based on the significance value (Sig.). A Sig. value lower than 0.05 indicated that there was a statistically significant difference between the pretest and posttest scores (Hajjah et al., 2022).

After the mean difference analysis, the improvement in students' learning outcomes was further examined using the normalized gain (N-gain) analysis. The N-gain was used to determine the extent to which students' learning outcomes improved after the implementation of the Assessment for Learning approach. The interpretation of N-gain scores is presented in Table 1.

Table 1. Interpretation of N-gain scores

N-gain score	Categories
$g < 0.3$	Low
$0.7 > g \geq 0.3$	Medium
$g \geq 0.7$	Height

(Adaptation: Hake, 1998)

Based on Table 1, when the N-gain value is at least in the medium category, assessment for learning is deemed successful in enhancing students' learning outcomes (Andriani & Gazali, 2025). The design of student

activity sheets (LAPD), which are created based on Assessment for Learning processes to enable active participation and tracking of students' learning progress, supports this implementation.

3. Results and Discussion

3.1. Result

The results of this study present the outcomes of instrument validity evaluation, reliability testing, and statistical analysis of students' learning outcomes before and after the implementation of the Assessment for Learning (AfL) approach. The findings include the results of expert validation, reliability analysis, descriptive statistics of pretest and posttest scores, normality testing, mean difference analysis, and normalized gain (N-gain) analysis.

3.1.1. Instrument Validity

The validity of the research instrument was evaluated through expert judgment involving three experts in chemistry education. The experts assessed the test items based on several aspects, including the alignment of the questions with learning indicators, the accuracy of chemical concepts, the clarity of language, and the suitability of the items for senior high school students. The results of the expert validation are presented in Table 2.

Table 2. Result of instrument content validity

Item Number	Validator 1 Score	Validator 2 Score	Validator 3 Score	Median	Category
1	4	4	4	4	Very Valid
2	4	4	3	4	Very Valid
3	4	3	3	3	Valid
4	4	4	4	4	Very Valid
5	4	3	4	4	Very Valid
6	4	4	3	4	Very Valid
7	4	4	4	4	Very Valid
8	3	3	4	3	Valid
9	3	4	3	3	Valid
10	4	3	4	4	Very Valid
11	4	4	3	4	Very Valid
12	4	4	4	4	Very Valid

Based on the content validity analysis presented in Table 2, the expert judgment results indicated that 9 test items were categorized as very valid, while the remaining 3 items were categorized as valid. The median scores of the items ranged from 3 to 4, indicating that all test items met the predetermined validity criteria. Since each item obtained a median score of ≥ 3, all items were considered valid and suitable for use in the research instrument. These results demonstrate that the instrument adequately represents the conceptual indicators and can be used to measure students' conceptual understanding of electrolyte and nonelectrolyte solutions.

3.1.2. Instrument Reability

The reliability of the instrument was analyzed using the Cronbach's Alpha coefficient with the assistance of SPSS software version 23. This analysis was conducted to determine the internal consistency of the test items and to ensure that the instrument consistently measured students' conceptual understanding of electrolyte and nonelectrolyte solutions. The results of the reliability analysis are presented in Table 3.

Table 3. Reliability Test Result

Instrument	Number of Items	Cronbach's Alpha	Category
Learning Outcome Test	12	0,82	High reliability

Based on Table 3, the Cronbach's Alpha coefficient obtained was 0.82. Since the value is greater than 0.70, the instrument can be categorized as reliable and has good internal consistency for measuring students' conceptual understanding.

3.1.3. Descriptive Statistics of Pretest and Posttest Scores

Students' learning outcomes were measured through pretest and posttest scores to determine the improvement in conceptual understanding after the implementation of the Assessment for Learning approach. The descriptive statistics of students' pretest and posttest scores are presented in Table 4.

Table 4. Descriptive statistics of pretest and postest scores of students

	N	Minimum	Maximum	Mean	Standard Deviation
Pretest	36	17.5	72.5	43.26	15.92
Posttest	36	82.5	95	89.72	3.91

Based on the descriptive analysis presented in Table 4, there was a substantial improvement in students' learning outcomes following the implementation of the Assessment for Learning (AfL) approach. The mean score increased significantly from 43.26 in the pretest to 89.72 in the posttest. Furthermore, the minimum score rose from 17.5 to 82.5, while the maximum score improved from 72.5 to 95. Notably, the standard deviation decreased from 15.92 to 3.91, indicating that students' scores became more consistent and the gap in conceptual understanding among students narrowed after the learning intervention.

3.1.4. Normality Test

Before conducting the hypothesis testing, a normality test was performed to determine whether the pretest and posttest data were normally distributed. Since the number of participants in this study was fewer than 50, the Shapiro–Wilk test was used to assess the distribution of the data. The results of the normality test for the pretest and posttest scores are presented in Table 5.

Table 5. Normality Test Result (Shapiro-Wilk)

	Mean	Standar Deviasi	N	Sig.
Pre-test	43.26	15.92	36	0.021
Post-test	89.72	3.90	36	0.004

Based on Table 5, the significance value of the pretest data was 0.021 and the posttest data was 0.004. Since both values were lower than 0.05, the data were considered not normally distributed. Therefore, a non-parametric statistical test, namely the Wilcoxon Signed Rank Test, was used to analyze the difference between the pretest and posttest scores.

3.1.5. Wilcoxon Signed Rank Test

Since the pretest and posttest data were not normally distributed, a non-parametric statistical test was used to examine the difference between the two sets of scores. In this study, the Wilcoxon Signed Rank Test was applied to determine whether there was a significant difference between students' pretest and posttest scores. The results of the Wilcoxon Signed Rank Test are presented in Table 6.

Table 6.Wilcoxon signed rank test result

	Z	Asymp. Sig. (2-tailed)
Pretest-Posttest	-5.235	0.000

Based on Table 6, the Wilcoxon Signed Rank Test produced a Z value of –5.235 with a significance value (Asymp. Sig. 2-tailed) of 0.000. Since the significance value is less than 0.05, it can be concluded that there is a statistically significant difference between the pretest and posttest scores. These results indicate that the implementation of the Assessment for Learning approach significantly improved students' learning outcomes on electrolyte and nonelectrolyte solution concepts.

3.1.6. N-Gain Analysis

To further determine the level of improvement in students' learning outcomes, normalized gain (N-gain) analysis was conducted. The results of the N-gain analysis are presented in Table 7.

Table 7. Distribution of students' N-gain scores

N-gain score	Frequency	Percentage (%)	Categories
$g < 0.3$	0	0	Low
$0.7 > g \geq 0.3$	3	8.33	Medium
$g \geq 0.7$	33	91.67	High

Based on Table 7, the majority of students were categorized in the high N-gain category, with 33 students (91.67%). Meanwhile, 3 students (8.33%) were categorized in the medium category, and no students were categorized in the low category. These findings indicate that the implementation of the Assessment for Learning approach effectively improved students' learning outcomes.

3.2. Discussion

This section discusses the findings of the study in relation to the research objectives and relevant theoretical perspectives. The discussion focuses on the quality of the research instrument, the effectiveness of the Assessment for Learning (AfL) approach in improving students' learning outcomes, the level of learning improvement based on the N-gain analysis, as well as the educational implications of implementing formative assessment strategies in chemistry learning, particularly on the topic of electrolyte and nonelectrolyte solutions.

3.2.1 Interpretation of Instrument Quality

The results of the instrument validation indicate that the developed test items met the required standards for content validity. Based on the expert judgment presented in Table 2, nine test items were categorized as very valid, while the remaining three items were categorized as valid. These findings indicate that the items appropriately represented the learning indicators related to electrolyte and nonelectrolyte solution concepts. The validation results also suggest that the items were clearly formulated, conceptually accurate, and aligned with the intended learning objectives.

Furthermore, the reliability analysis presented in Table 3 showed a Cronbach's Alpha coefficient of 0.82, indicating a high level of internal consistency among the test items. A reliability value above 0.70 is generally considered acceptable in educational research, indicating that the instrument consistently measures the intended construct. The strong combination of validity and reliability demonstrates that the developed instrument was suitable for measuring students' conceptual understanding of electrolyte and nonelectrolyte solutions. Well-designed assessment instruments are essential in chemistry education, particularly when evaluating students' understanding of abstract concepts that involve multiple levels of chemical representation.

3.2.2 Effect of the Assessment for Learning Approach on Students' Learning Outcomes

The statistical analysis revealed a significant difference between students' pretest and posttest scores, as indicated by the Wilcoxon Signed Rank Test results presented in Table 6. The significance value (Asymp. Sig. 2-tailed) was 0.000, which is lower than the significance level of 0.05. This finding indicates that the implementation of the Assessment for Learning (AfL) approach significantly improved students' learning outcomes on electrolyte and nonelectrolyte solution material. This result is also supported by the descriptive statistics in Table 4, which show that the mean score increased substantially from 43.26 in the pretest to 89.72 in the posttest.

In the context of chemistry learning, the improvement in students' learning outcomes can also be explained through the role of formative assessment in supporting multirepresentational understanding (Mandouit & Hattie, 2023). Chemistry concepts are commonly represented through three levels of representation: macroscopic, submicroscopic, and symbolic representations (Brookhart & McMillan, 2020). The topic of electrolyte and nonelectrolyte solutions requires students to connect observable phenomena, such as the ability of a solution to conduct electricity (macroscopic level), with particle-level explanations involving the dissociation of substances into ions in aqueous solutions (submicroscopic level), as well as symbolic representations such as ionization equations and chemical formulas (symbolic level). Through the Assessment for Learning approach, students were actively involved in discussions, worksheet-based activities, and reflection tasks that allowed them to continuously receive feedback on their reasoning. These formative interactions helped students gradually refine their understanding and connect these three levels of representation more effectively (Anderson, 2003).

Furthermore, the effectiveness of the AfL approach can be attributed to the continuous feedback provided during the learning process (Adie et al., 2018). Through formative assessment practices, teachers can identify students' misconceptions and provide immediate feedback that guides students toward a more accurate conceptual understanding. According to research by Black and Wiliam (1998), formative assessment practices significantly improve students' learning outcomes by integrating assessment directly into the learning process. Similarly, feedback-oriented learning environments have been shown to enhance students' engagement and promote deeper conceptual reasoning (Nicol & Macfarlane-Dick, 2006; Hattie & Timperley, 2007). These findings support the results of this study, indicating that the Assessment for Learning approach can effectively support students' conceptual development in chemistry learning.

3.2.3 Improvement of Students' Learning Outcomes Based on N-Gain Analysis

The N-gain analysis results presented in Table 7 further confirm the effectiveness of the Assessment for Learning approach in improving students' conceptual mastery. The majority of students (91.67%) achieved a high N-gain category, while the remaining students (8.33%) were categorized in the medium category. No

students were found in the low category. This distribution indicates that the learning intervention successfully facilitated substantial learning improvement among students (Hasanah & Muchlis, 2024).

The high level of improvement observed in this study may be explained by the active learning environment created through the AfL approach. Students were encouraged to participate in discussions, analyze problems collaboratively, and reflect on their understanding during the learning process. Such learning activities allow students to construct their own understanding rather than passively receiving information from the teacher. In the context of electrolyte and nonelectrolyte solutions, students must understand that electrolyte solutions dissociate into ions that enable electrical conductivity, whereas nonelectrolyte solutions remain as neutral molecules and therefore do not conduct electricity. Through continuous formative feedback and guided learning tasks, students were able to connect experimental observations with the underlying particle interactions and symbolic chemical representations. This process helps students develop a more integrated and meaningful understanding of the concept (Safithri & Muchlis, 2022).

3.2.4 Educational Implication

The findings of this study provide important implications for chemistry education, particularly in teaching abstract concepts such as electrolyte and nonelectrolyte solutions (Westbroek et al., 2020). The results demonstrate that integrating formative assessment practices through the Assessment for Learning approach can effectively support students' conceptual understanding by continuously monitoring their learning progress and providing timely feedback. Through AfL strategies such as classroom discussions, collaborative learning tasks, and reflective activities, students are encouraged to actively engage in the learning process and take responsibility for their own learning (Andriani & Gazali, 2025).

From a broader science education perspective, the implementation of Assessment for Learning supports inquiry-based learning environments in which students actively construct scientific explanations rather than simply memorizing factual information (Flórez & Sammons, 2013). Such learning environments promote the development of scientific literacy, critical thinking, and problem-solving skills, which are essential competencies in modern science education. By incorporating formative assessment into classroom instruction, teachers can create more responsive learning environments that help students develop deeper conceptual understanding of scientific phenomena (Nicol & Macfarlane-Dick, 2006).

4. Conclusion

The implementation of the Assessment for Learning (AfL) approach in teaching electrolyte and nonelectrolyte solutions proved to be an effective strategy for improving students' learning outcomes, as evidenced by the statistically significant increase in the mean score from 43.26 to 89.72. The Wilcoxon signed-rank test results (Asymp. Sig. 2-tailed = 0.000) and the high N-gain achievement of 91.67% of students confirm that the integration of clear learning objectives, classroom discussions supported by lstudent activity sheets, and continuous formative feedback successfully encouraged students to become more actively involved in their learning process. These findings contribute to chemistry education by demonstrating that the systematic implementation of formative assessment practices can help students bridge the relationships between macroscopic, submicroscopic, and symbolic representations when learning abstract chemical concepts. Practically, this research suggests that shifting from traditional teacher-centered instruction toward an integrated formative assessment approach enables teachers to identify and address students' misconceptions during the learning process. Ultimately, the application of Assessment for Learning strategies can support more meaningful conceptual understanding and foster a more responsive learning environment that accommodates students with different levels of prior knowledge.

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Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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