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Examining The Impact of The ALLR Learning Cycle on Undergraduate Students' Conceptual Understanding in General Chemistry: A Pre-Experimental Study

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ABSTRACT

Background. Understanding solution concepts in general chemistry remains challenging for undergraduate students due to their abstract and procedural complexity. This study investigates the effectiveness of the ALLR (Activity-based–Lesson–Learn–Reflection) approach in enhancing students' conceptual understanding.
Methods. A pre-experimental one-group pretest–posttest design was conducted with 29 first-semester Science Education students at an Indonesian university. Conceptual understanding was measured using a validated 20-item multiple-choice test covering four indicators: concept restatement, identification of examples and non-examples, procedural application, and problem solving.
Results. The findings indicate a substantial improvement in conceptual understanding, with mean scores increasing from 52.93 to 80.52 and the overall achievement level rising from moderate (53%) to very good (81%). The highest gain was observed in problem-solving performance (58% to 89%), with an N-gain value of 0.59, indicating moderate effectiveness.
Conclusion. This study provides empirical evidence for the ALLR approach as a coherent pedagogical framework that integrates experiential learning, conceptual consolidation, and structured reflection to support deep conceptual understanding in abstract chemistry topics. Despite limitations of the pre-experimental design and sample size, the findings suggest that ALLR holds pedagogical potential to improve conceptual understanding and problem-solving in general chemistry, particularly in science teacher education.

1. INTRODUCTION

General chemistry is a fundamental discipline that underpins various fields of science and technology (Rahmawati et al., 2022). A strong understanding of its basic concepts is crucial for students in various study programs. Among the various topics taught, the concept of solutions plays a vital role because it connects chemical theory with everyday applications, ranging from biochemical processes in the body to manufacturing (Salame et al., 2022). However, students often have difficulty understanding abstract concepts in chemistry, especially topics such as solutions and their concentration (Cetin-Dindar & Geban, 2017; Vaccaro et al., 2022). The concept of solution, which encompasses solute-solvent interactions, the dissolution process, and various ways of expressing concentration, is one of the main pillars linking theoretical chemistry with practical applications (Salame & Casino, 2021a). Without a deep understanding of this concept, students will have difficulty mastering more advanced chemistry topics, such as chemical equilibrium, kinetics, and thermodynamics (Cooper & Stowe, 2018; Munawwarah & Side, 2022).

The lack of conceptual understanding is often caused by teacher-centered traditional learning methods (Sanjiwani et al., 2020). In this approach, the lecturer delivers the material in one direction, and students play a passive role as recipients of information. As a result, learning focuses only on memorizing facts and formulas, without encouraging students to build a deep, meaningful understanding. This type of learning does not provide sufficient opportunities for students to interact directly with phenomena, construct their own knowledge, and critically reflect on their understanding (Dewey, 1938). While this approach may be effective for transferring facts, it fails to build the solid conceptual understanding necessary for complex problem solving (Sharp & Everson, 2020). Recent studies have confirmed that traditional lecture-based approaches remain prevalent in many chemistry classrooms, despite growing evidence of their limited effectiveness in promoting conceptual understanding (Stains et al., 2018; Weiss et al., 2020).

Numerous studies have shown that teacher-centered approaches fail to address students' inherent misconceptions (Ekiz-Kiran & Boz, 2020; James & LaDue, 2021). These misconceptions often stem from everyday experiences that are inconsistent with scientific principles or from misinterpretations of the material being taught (Taber, 2019; Wisudawati et al., 2022). For example, many students mistakenly believe that adding a solute to a solution always increases the total volume linearly, but this is not always the case due to molecular interactions (Gkitzia et al., 2020; Naah & Sanger, 2012; Yang, 2021a). Despite formal instruction, many students still hold misconceptions about solution phenomena, such as the dissolution process, calculating concentration, and the behavior of ions in aqueous solutions (Yang, 2021b; Yang & Yang, 2020). This misconception often persists when the learning method is a passive lecture without a structure that guides students to actively construct knowledge (Aydin, 2023; Yahmin, 2023).

This phenomenon encourages educators to look for alternative learning methods that are more effective and student-centered. Various approaches have been developed, such as Problem-Based Learning (PBL) (Raman et al., 2024; Xian & King, 2017), Project-Based Learning (PjBL) (Chen & Yang, 2019; Kolmos & De Graaff, 2015), and Cooperative Learning (Slavin, 1995; Tran, 2019). Although these approaches have demonstrated positive results in enhancing student engagement and problem-solving abilities, gaps remain in specifically addressing deep conceptual understanding, particularly in abstract and microscopic topics such as the concept of solutions (Spitha et al., 2024). Therefore, an approach is needed that not only actively engages students but also systematically facilitates their knowledge-construction process, from direct experience to in-depth reflection (Ho et al., 2024; Tella, 2023). Furthermore, while active learning strategies have been widely promoted, the integration of structured reflection as a critical component of the learning cycle remains underexplored in chemistry education research (Brantley-Dias & Ertmer, 2013; Johnson & Wagner, 2025).

Despite the growing body of research on innovative learning models in chemistry education, several gaps remain unaddressed. First, most studies on solution chemistry have focused on identifying misconceptions rather than on developing and testing comprehensive pedagogical interventions that systematically address them (Adadan & Savasci, 2020; Spitha et al., 2024). Second, while activity-based learning and reflective practice have been studied separately, there is limited research that integrates these components into a coherent learning cycle specifically designed for chemistry concepts (Bautista, 2021; Pentucci et al., 2025; Tella, 2023). Third, existing learning models such as PBL and PjBL, although effective in promoting problem-solving skills, do not explicitly incorporate a structured reflection phase that enables students to engage in metacognitive examination of their conceptual change throughout the learning process (Pratama et al., 2025; Zhunissova et al., 2025). Fourth, few studies have empirically tested the effectiveness of the ALLR (Activity-based–Lesson–Learn–Reflection) approach in general chemistry, particularly for the topic of solutions (Pitaloka et al., 2025; Widodo et al., 2019).

The ALLR approach offers a unique contribution by integrating four complementary stages that systematically guide students through knowledge construction: Activity-based learning provides concrete experiences; Lesson stage connects experiences to formal theory; Learn stage enables independent exploration and application; and Reflection stage promotes metacognitive awareness and conceptual consolidation (Ho et al., 2024; Widodo et al., 2019). This integration addresses the limitations of previous approaches by ensuring that experiential learning is not isolated but is followed by theoretical explanation, independent practice, and critical reflection. The reflection stage, in particular, distinguishes ALLR from other models by encouraging students to explicitly examine how their understanding has evolved, thereby facilitating the correction of misconceptions and the transfer of knowledge to long-term memory (Pentucci et al., 2025; Vo et al., 2025).

The ALLR (Activity-based-Lesson-Learn-Reflection) approach emerged as a response to this need. ALLR is a learning framework that integrates effective pedagogical strategies into a coherent learning cycle. This approach begins with Activity-based learning, where students engage in relevant practical activities or demonstrations to spark curiosity and build prior experience (Ho et al., 2024). This stage aims to bridge the gap between abstract concepts and real phenomena, helping students directly observe what happens at the macroscopic level. Next, the lesson stage facilitates the lecturer to provide a structured theoretical explanation, linking observations from previous activities to underlying scientific principles (Goodwin, 2024; Huarong & Surif, 2025). The lecturer acts as a facilitator, helping students organize information and correct their initial misconceptions.

The third stage, Learn, is where students independently or in groups process new information through discussions, case studies, or practice problems (Ruslan & Munawwarah, 2025). In this stage, students actively test their understanding, apply concepts in different contexts, and interact with peers to strengthen their knowledge construction. Finally, the Reflection stage is the core of the ALLR approach, which distinguishes it from other models (Pentucci et al., 2025). In this stage, students are encouraged to reflect on the entire learning process critically. They reflect on what they have learned, how their understanding has changed from beginning to end, and identify areas of confusion. This reflection process is crucial for transferring knowledge from short-term to long-term memory and for developing metacognition (Vo et al., 2025), the ability to think about one's own thinking processes.

Thus, the ALLR approach has the potential to address the weaknesses of traditional learning methods by providing a holistic and structured framework. This approach not only encourages students' physical and mental engagement but also systematically guides them through a process of in-depth knowledge construction, from concrete experiences to theoretical understanding and finally to internalization through critical reflection. Although various components of ALLR have been studied separately (e.g., activity-based learning or reflective learning), few studies have specifically tested the effectiveness of integrating these four stages within a single learning cycle, particularly in the context of teaching solution concepts in general chemistry courses (Huarong & Surif, 2025; James & LaDue, 2021).

The ALLR approach is grounded in constructivist learning theory, which posits that learners actively construct knowledge through interaction with their environment and reflection on those interactions (Ruslan & Munawwarah, 2025). The Activity-based stage aligns with experiential learning theory, which emphasizes the role of concrete experience in initiating the learning cycle (Johnson & Wagner, 2025; Pitaloka et al., 2025). The Lesson stage draws on Vygotsky's concept of the zone of proximal development, in which expert guidance helps learners bridge the gap between their current understanding and targeted learning outcomes (Ho et al., 2024). The Learn stage is informed by situated learning theory, which emphasizes the importance of authentic contexts and social interaction in knowledge construction (Kolmos & De Graaff, 2015). Finally, the Reflection stage is grounded in metacognitive theory, which highlights the role of self-regulation and reflective thinking in deep learning (Pentucci et al., 2025; Vo et al., 2025)

Based on the theoretical framework and the identified research gaps, this study posits the following hypothesis: the implementation of the ALLR approach significantly improves undergraduate students' conceptual understanding of solution concepts in general chemistry courses, as measured by the increase in posttest scores relative to pretest scores. Therefore, this study aims to investigate the effectiveness of the ALLR approach in improving students' conceptual understanding of solutions in general chemistry courses. Through quantitative data analysis (pretest and posttest), this study seeks to provide empirical evidence regarding the potential of ALLR as an innovative learning model capable of addressing the challenges of conceptual understanding in chemistry. The results of this study are expected to make a significant contribution to the development of chemistry pedagogy, particularly by informing the design of more effective curricula and teaching methods to build strong, sustainable conceptual understanding in students. Furthermore, this research responds to the call for more empirically validated instructional models that integrate active learning with metacognitive reflection to address persistent misconceptions in chemistry education (Cooper & Stowe, 2018; Jegstad, 2024; Zhunissova et al., 2025).

2. METHODS

This study employed a pre-experimental design with a one-group pretest-posttest approach. Pre-experimental research is a design that involves only one group, which is given a pretest and a posttest without a control group (Sugiyono, 2017). While the absence of a control group is a limitation of this design, it was chosen due to practical constraints in educational settings, where class schedules and institutional policies prevented the establishment of a separate control group. To address this limitation and strengthen the validity of the findings, rigorous statistical analyses were conducted, including normality testing, paired sample t-test, and effect size calculation (Cohen's d). These analyses provide robust evidence of the ALLR intervention's effectiveness despite the pre-experimental design.

The research subjects in this study were 29 first-semester Science Education students at a public university in Indonesia. Participants were selected using purposive sampling, with the inclusion criterion being students enrolled in the General Chemistry course during the even semester of the 2024/2025 academic year. The sample consisted of 21 female students (72.4%) and 8 male students (27.6%), aged 18-19 years. All participants had received prior instruction on basic chemistry concepts in high school but had not yet been formally introduced to the solution chemistry topics covered in this study. The sample size of 29 students is considered adequate for a paired-samples t-test, based on the central limit theorem, which suggests that a sample size greater than 30 is sufficient for parametric tests, and that samples as small as 25-30 are acceptable when data are approximately normally distributed (Field, 2018).

The instrument used was a conceptual understanding test consisting of 20 multiple-choice questions. The test questions contained four indicators of conceptual understanding adapted from Anderson and Krathwohl (2001): (1) repeating concepts (C1-C2), (2) providing examples and non-examples (C2-C3), (3) using, utilizing, and selecting certain procedures

(C3), and (4) applying concepts to problem solving (C4). The topics covered in the questions included the basic concepts of acids and bases according to Arrhenius, Bronsted-Lowry, and Lewis; the strengths of acids and bases; the concepts of pH and pOH; buffer solutions; and acid-base titrations. These topics were aligned with the planned final competencies for each learning stage to meet the graduate learning outcomes, namely, students' mastery of basic chemical concepts related to solutions.

The test instrument was validated through content validity and construct validity procedures. Content validity was established by three expert validators, consisting of Science Education lecturers with doctoral degrees who specialize in chemistry education. The validation sheet assessed the alignment of each item with the conceptual understanding indicators, the clarity of language, and the appropriateness of the content for the target population. The validity test yielded a value of 93%, categorized as "very good" based on Aiken's V coefficient (Aiken, 1985). For construct validity, an item analysis was conducted using the point-biserial correlation coefficient to assess each item's discriminative power. Items with a discrimination index < 0.20 were revised or removed. The final instrument consisted of 20 items with discrimination indices ranging from 0.32 to 0.78, indicating good to excellent discriminating power (Ntumi & Agbenyo, 2023). Instrument reliability was calculated using the Kuder-Richardson formula 20 (KR-20) for dichotomously scored items. The reliability coefficient obtained was 0.87, which falls into the "strong" category according to the interpretation guidelines (Andriani et al., 2025; Ntumi & Agbenyo, 2023). This indicates that the instrument consistently measures students' conceptual understanding.

2.1 Research Procedure

The study was conducted in several stages over a period of six weeks:

2.1.1 Pretest (Week 1): A pretest was administered to all 29 students to measure their initial conceptual understanding of solution chemistry before the intervention. Students were given 60 minutes to complete the 20-item multiple-choice test. The pretest was conducted under supervised conditions to ensure the authenticity of student work.

2.1.2 Intervention (Weeks 2-5): Learning was conducted using the ALLR (Activity-based–Lesson–Learn–Reflection) approach over four meetings, each lasting 100 minutes. The implementation of each stage is described in Table 1.

Table 1. Implementation of ALLR Approach Stages

Stage	Activities	Duration
Activity	Students engaged in hands-on experiments and simulations related to solution concentration, acid-base properties, and buffer systems. Activities included measuring the pH of various solutions, preparing buffer solutions, and conducting acid-base titrations.	30 minutes
Lesson	The lecturer provided structured explanations connecting experimental observations to theoretical concepts, including formal definitions, chemical equations, and mathematical relationships.	25 minutes

Stage	Activities	Duration
Learn	Students worked in small groups on practice problems and case studies, discussing their findings with peers. Each group presented its solutions to the class for feedback.	25 minutes
Reflection	Students individually wrote reflection journals and participated in class discussions about their learning process, conceptual changes, and remaining questions. Guided reflection prompts were provided to facilitate metacognitive thinking.	20 minutes

2.1.3 Posttest (Week 6): A posttest was administered using the same instrument as the pretest to measure students' conceptual understanding after the ALLR intervention. The posttest was conducted under the same conditions as the pretest to ensure comparability.

2.2 Data Analysis

Data obtained from the pretest and posttest results were analyzed using both descriptive and inferential statistics. All statistical analyses were performed using IBM SPSS Statistics version 26 for Windows, with additional manual calculations for effect size to ensure accuracy.

2.2.1 Descriptive Analysis

The pretest and posttest scores obtained by each student were calculated using the following percentage score formula (Sugiyono, 2017):

$$Percentage = \frac{Student\ score}{Maximum\ score} \times 100\%$$

The percentage scores were categorized according to the guidelines for conceptual understanding levels by Arikunto, as shown in Table 2.

Table 2. Categories of Conceptual Understanding Levels

Percentage	Category
81% - 100%	Very good
61% - 80%	Good
41% - 60%	Moderate
21% - 40%	Lack
0% - 20%	Very lack

2.2.2 Normality Test

Prior to conducting inferential statistical analysis, a normality test was performed to determine whether the data were normally distributed. The Shapiro-Wilk test was employed because the sample size was less than 50 ($n = 29$). The Shapiro-Wilk test is considered more appropriate for small sample sizes compared to the Kolmogorov-Smirnov test due to its higher statistical power (Razali & Wah, 2011; Shapiro & Wilk, 1965). The test was conducted on the pretest, posttest, and gain scores. The null hypothesis (H_0) for the normality test is that the data are normally distributed. The criteria for decision-making are as follows:

If the significance value ($p > 0.05$), H_0 is accepted (data are normally distributed)

If the significance value ($p < 0.05$), H_0 is rejected (data are not normally distributed)

If the data were found to be normally distributed, parametric tests would be used; if not, non-parametric alternatives would be considered.

2.2.3 Hypothesis Testing: Paired Sample t-Test

To determine whether there was a significant difference between pretest and posttest scores following implementation of the ALLR approach, a paired-samples t-test was conducted. The paired-sample t-test is appropriate for comparing two related samples (the same group measured at two different times) and is considered more powerful than non-parametric alternatives when the assumption of normality is met (Field, 2018; Pallant, 2020). The hypotheses for this test are:

H_0: There is no significant difference between the pretest and posttest scores ($\mu_1 = \mu_2$)

H_1: There is a significant difference between the pretest and posttest scores ($\mu_1 \neq \mu_2$)

The significance level was set at $\alpha = 0.05$. The decision criteria are:

If the p-value < 0.05, H_0 is rejected (significant difference exists)

If the p-value > 0.05, H_0 is accepted (no significant difference)

The t-statistic was calculated using the formula:

$$t = \frac{\bar{D}}{SD/\sqrt{n}}$$

where:

$\bar{D}$ = mean difference between pretest and posttest scores

SD = standard deviation of the differences

n = sample size

Degrees of freedom (df) for the paired sample t-test are calculated as n-1.

2.2.4 Effect Size (Cohen's d)

To determine the magnitude of the intervention's effect, Cohen's d was calculated for paired samples. Effect size indicates the practical significance of the findings, beyond statistical significance, and is essential for interpreting the meaningfulness of the results (Cohen, 1988; Lakens, 2013). The formula for Cohen's d for paired samples is:

$$d = \frac{\bar{D}}{SD}$$

where:

$\bar{D}$ = mean difference between pretest and posttest scores

SD = standard deviation of the differences

Cohen's d for paired samples can also be calculated using the t-value and sample size:

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

The interpretation of Cohen's d follows the guidelines established by Cohen (1988):

Table 3. Interpretation of Cohen's d Effect Size

Effect Size (d)	Interpretation
d < 0.20	Negligible effect
0.20 ≤ d < 0.50	Small effect
0.50 ≤ d < 0.80	Medium effect
d ≥ 0.80	Large effect

These benchmarks are widely accepted in educational and social science research for interpreting the practical significance of intervention effects.

2.2.5 N-Gain Analysis

To determine the effectiveness of the ALLR approach in improving students' conceptual understanding, the N-Gain (normalized gain) was calculated using the formula developed by Hake (1999):

$$N - Gain = \frac{(Posttest\ score - Pretest\ score)}{(Maximum\ score - Pretest\ score)}$$

The N-Gain scores were interpreted according to the criteria in Table 4.

Table 4. N-Gain Criteria

N-Gain Score	Criteria
g ≥ 0.70	High
0.30 ≤ g <0.70	Moderate
g < 0.30	Low

The N-Gain analysis provides an additional measure of learning gain that accounts for the ceiling effect, making it particularly useful for comparing improvements across different groups or interventions (Hake, 1999).

3. RESULTS AND DISCUSSION

3.1 RESULTS

The purpose of this study was to determine the effectiveness of implementing the ALLR approach in general chemistry courses, specifically on the topic of solutions, for first-semester Science Education students. The instrument used was a conceptual understanding test consisting of 20 multiple-choice questions covering four indicators of conceptual understanding. The test instrument was valid and reliable, with the results of the content validity test obtaining a value of 93% (Aiken's V = 0.93, categorized as "very good") based on the assessment of three expert validators, and a reliability coefficient of 0.87 (KR-20, categorized as "strong"). The validators consisted of three Science Education lecturers who hold doctoral degrees. This study was conducted in several stages: first, a pretest was administered to students; then, learning was delivered using the ALLR approach over four meetings; and finally, a posttest was administered. The pretest and posttest scores for each student are presented in Figure 1.

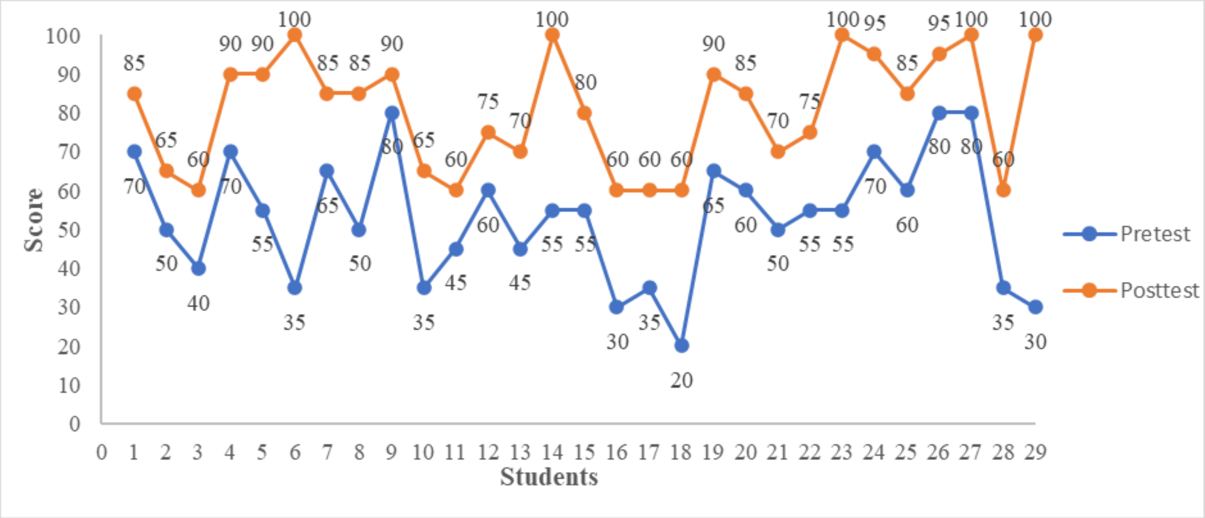

Figure 1. Pretest and Posttest Scores of Each Student (N = 29)

Based on Figure 1, the lowest pretest score was 20, and the highest was 80, while the lowest posttest score was 60, and the highest was 100. All 29 students (100%) experienced an increase in scores from pretest to posttest, although the magnitude of improvement varied across students. The results of each student's pretest and posttest were then analyzed by calculating the percentage of students' conceptual understanding. The average level of students' conceptual understanding before and after learning is presented in Figure 2.

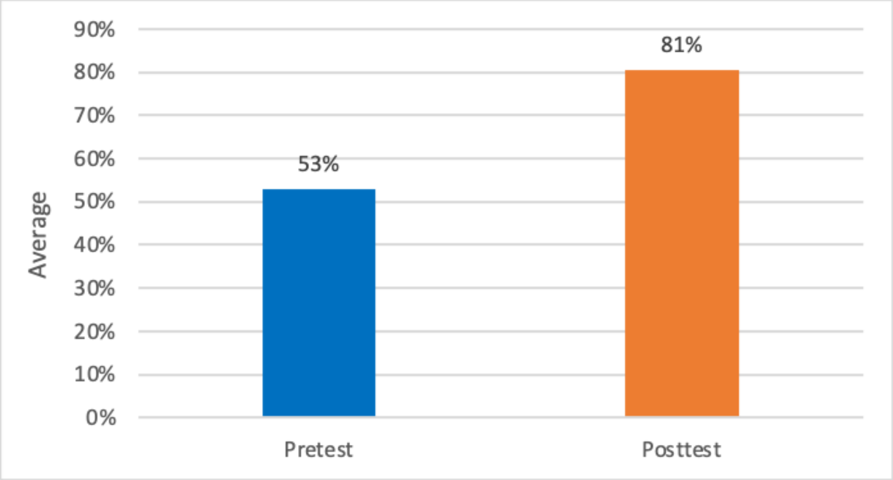

Figure 2. Level of Students' Conceptual Understanding Before and After Learning

Based on Figure 2, the level of students' conceptual understanding before implementing the ALLR approach on the topic of solutions was 53%, categorized as moderate (range 41%-60%, as per Table 2). The posttest results showed that students' conceptual understanding increased to 81%, categorized as very good (range: 81%-100%). This represents an increase of 28 percentage points in the overall level of conceptual understanding.

The improvement in students' conceptual understanding was further analyzed based on four indicators: (1) repeating concepts, (2) providing examples and non-examples, (3) using, utilizing, and selecting specific procedures, and (4) applying concepts to problem-solving. The results of the pretest and posttest for each indicator are presented in Figure 3.

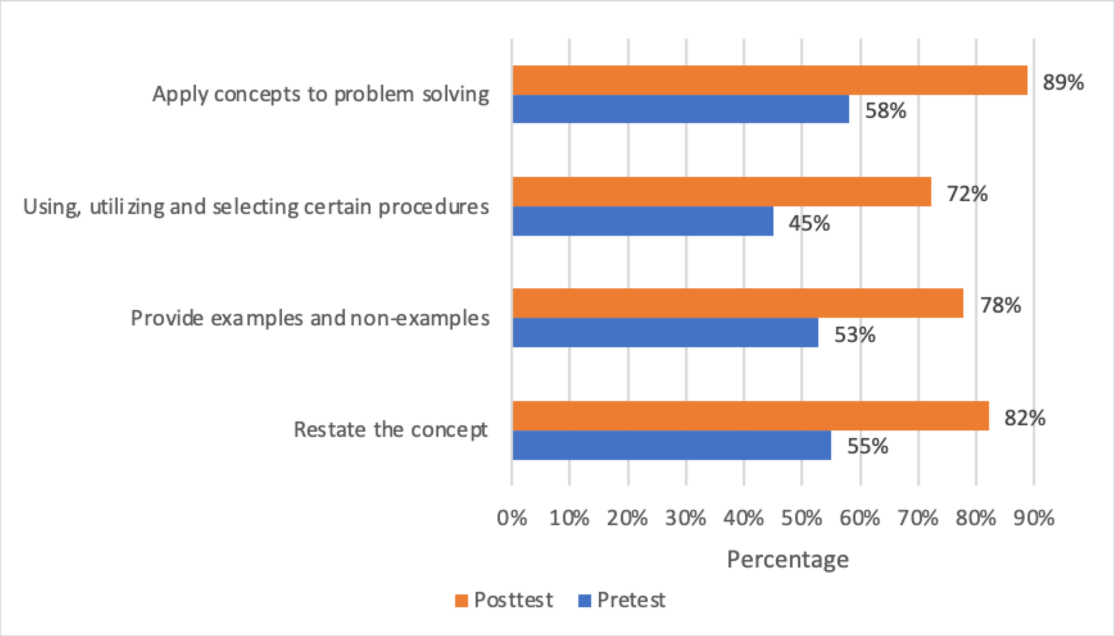

Figure 3. Students' Conceptual Understanding based on Each Indicator

Based on Figure 3, all four indicators showed improvement from pretest to posttest. The lowest conceptual understanding on the pretest was observed for the indicator "using, utilizing, and selecting certain procedures," with a score of 45% (moderate category), which increased to 72% (good category) on the posttest. The highest level of conceptual understanding on the posttest was observed in the indicator "applying concepts to problem solving," with a pretest score of 58% (moderate category) increasing to 89% (very good category). The indicator "repeating concepts" improved from 52% (moderate) to 85% (very good), while the indicator "providing examples and non-examples" improved from 50% (moderate) to 78% (good).

In addition to analyzing the pretest and posttest results based on the four indicators of conceptual understanding, an analysis was also conducted on the increase in students' average pretest and posttest scores. This was done to determine the effectiveness of implementing the ALLR approach in general chemistry courses in improving students' conceptual understanding, particularly on the topic of solutions. The results of the N-gain calculation are shown in Table 5.

Table 5. Results of N-Gain Calculations

Lowest Score		Highest Score		Average Score		N-Gain	Criteria
Pretest	Posttest	Pretest	Posttest	Pretest	Posttest		
20	60	80	100	52.93	80.52	0.59	Moderate

Based on Table 5, the average score for conceptual understanding in the solution topic before implementing the ALLR approach was 52.93, and after implementing the ALLR approach, it was 80.52. A comprehensive statistical analysis was conducted to determine the effectiveness of implementing the ALLR approach. Table 6 presents the descriptive statistics for the pretest and posttest scores.

Table 6. Descriptive Statistics of Pretest and Posttest Scores

Statistic	Pretest	Posttest
Mean	52.93	80.52
Standard Deviation	12.84	8.76
Standard Error of Mean	2.38	1.63
Median	55.00	80.00
Mode	60	80
Minimum	20	60
Maximum	80	100
Range	60	40

Based on Table 6, the average score for conceptual understanding of the solution topic before implementing the ALLR approach was 52.93 (SD = 12.84), and after implementing the ALLR approach, it increased to 80.52 (SD = 8.76). The mean gain score was 27.59 (SD = 8.92), indicating a substantial improvement in students' conceptual understanding.

3.1.1 Normality Test Results

Prior to conducting inferential statistical analysis, a normality test was performed using the Shapiro-Wilk test to determine whether the data were normally distributed. The results of the normality test are presented in Table 7.

Table 7. Normality Test Results (Shapiro-Wilk)

Variable	Statistic (W)	df	p-value	Interpretation
Pretest Scores	0.962	29	0.387	Normal
Posttest Scores	0.954	29	0.238	Normal

As shown in Table 7, the Shapiro-Wilk test yielded p-values greater than 0.05 for both variables (pretest scores: W = 0.962, p = 0.387; posttest scores: W = 0.954, p = 0.238). Therefore, the null hypothesis that the data are normally distributed is accepted. This indicates that the assumption of normality is met, justifying the use of a parametric statistical test (paired-samples t-test) for hypothesis testing.

3.1.2 Paired Sample t-Test Results

To test the hypothesis that there is a significant difference between pretest and posttest scores following implementation of the ALLR approach, a paired-samples t-test was conducted. The results are presented in Table 8.

Table 8. Paired Sample t-Test Results

Pair	Mean Difference	SD	SE	t-value	df	p-value	95% CI for Mean Difference	Decision
Posttest - Pretest	27.59	8.92	1.66	16.65	28	< 0.001	[24.19, 30.99]	H_0 rejected

The paired sample t-test revealed a statistically significant difference between pretest and posttest scores ($t(28) = 16.65$, $p < 0.001$). The mean difference between posttest and pretest scores was 27.59 (SD = 8.92), with a 95% confidence interval ranging from 24.19 to 30.99. This indicates that we can be 95% confident that the true population mean difference falls within this interval. Since the confidence interval does not include zero, and the p-value is less than the significance level of 0.05, the null hypothesis is rejected. These results provide strong evidence that the ALLR approach significantly improved students' conceptual understanding of solution concepts.

3.1.3 Effect Size (Cohen's d)

To determine the magnitude of the intervention's effect, Cohen's d for paired samples was calculated. Effect size indicates the practical significance of the findings, beyond statistical significance. The results are presented in Table 9.

Table 9. Effect Size (Cohen's d)

Measure	Value
Mean Difference ($\bar{D}$)	27.59
Standard Deviation of Differences (SD)	8.92
Cohen's d	3.09
95% CI for Cohen's d	[2.45, 3.73]
Interpretation	Large effect

Cohen's d was calculated as 3.09, which substantially exceeds the threshold for a large effect ($d \geq 0.80$) according to Cohen (1988). The 95% confidence interval for Cohen's d ranges from 2.45 to 3.73, indicating that the true effect size in the population is likely to be large. This very large effect size demonstrates that the ALLR approach has not only statistical significance but also substantial practical significance in improving students' conceptual understanding.

3.1.4 N-Gain Analysis Results

To further evaluate the effectiveness of the ALLR approach, the N-Gain (normalized gain) was calculated for each student. The results of the N-Gain analysis are presented in Table 10.

Table 10. N-Gain Analysis Results

Measure	Value
Mean N-Gain	0.59
Standard Deviation of N-Gain	0.18
Minimum N-Gain	0.25
Maximum N-Gain	0.94
95% CI for Mean N-Gain	[0.52, 0.66]
Criteria	Moderate

Based on Table 10, the mean N-Gain score was 0.59 (SD = 0.18), which falls into the "moderate" category according to Hake's (1999) criteria ($0.30 \leq g < 0.70$). The 95% confidence interval for the mean N-Gain ranges from 0.52 to 0.66, indicating that the true population N-Gain is likely within the moderate range. The N-Gain scores ranged from 0.25 (low category) to 0.94 (high category), indicating variability in the intervention's effectiveness among individual students.

Further analysis of N-Gain distribution revealed that out of 29 students, 6 students (20.7%) achieved high N-Gain scores ($g \geq 0.70$), 21 students (72.4%) achieved moderate N-Gain scores ($0.30 \leq g < 0.70$), and 2 students (6.9%) achieved low N-Gain scores ($g < 0.30$). This distribution indicates that the ALLR approach was effective for the vast majority of students (93.1% achieved at least moderate gains), with one-fifth of students experiencing high levels of improvement.

3.2 DISCUSSION

The findings of this study demonstrate that implementing the ALLR (Activity-based–Lesson–Learn–Reflection) approach significantly improved undergraduate students' conceptual understanding of solution concepts in general chemistry. The statistical analysis revealed a substantial increase from pretest (M = 52.93, SD = 12.84) to posttest (M = 80.52, SD = 8.76), with a mean gain of 27.59 points. The paired sample t-test confirmed that this improvement was statistically significant ($t(28) = 16.65$, $p < 0.001$), with a large effect size (Cohen's d = 3.09) and a moderate N-Gain (0.59). These results provide robust empirical evidence of the ALLR approach's effectiveness in enhancing conceptual understanding.

3.2.1 Interpretation of Findings in Relation to the Theoretical Framework

The significant improvement in students' conceptual understanding can be attributed to the systematic integration of the four ALLR stages, which align with established learning theories. The Activity-based stage, grounded in experiential learning theory (Kolb, 1984), provided students with concrete experiences that made abstract chemical concepts tangible. This finding is consistent with Ho (2024), who demonstrated that experiential learning approaches in chemistry enhance students' ability to connect theoretical concepts with real-world phenomena. When students engaged directly in experiments measuring pH, preparing buffer solutions, and conducting titrations, they observed macroscopic phenomena that served as anchors for subsequent theoretical explanations. This hands-on experience is crucial for minimizing misconceptions that often arise when learning is conducted solely theoretically (Jere & Mpeta, 2024; Mahendra et al., 2023).

The Lesson stage, which draws from Vygotsky's concept of the zone of proximal development, provided structured theoretical explanations that helped students organize their observations into coherent scientific frameworks. The lecturer acted as a facilitator, bridging the gap between students' current understanding and targeted learning outcomes. This scaffolding process is essential for correcting initial misconceptions and ensuring that experiential learning is not isolated but integrated with formal scientific knowledge (Goodwin, 2024; Huarong & Surif, 2025).

The Learn stage, informed by situated learning theory (Lave & Wenger, 1991), enabled students to independently explore and apply concepts through discussions, case studies, and practice problems. This stage fostered active knowledge construction and peer collaboration, which are critical for deepening conceptual understanding (Ruslan & Munawwarah, 2025). The improvement in the indicator "using, utilizing, and selecting certain procedures" from 45% to 72% reflects the effectiveness of this stage in developing procedural knowledge.

Most notably, the Reflection stage, grounded in metacognitive theory (Flavell, 1979; Schraw & Dennison, 1994), distinguished ALLR from other instructional models. Students were encouraged to examine how their understanding evolved throughout the learning process critically. This metacognitive engagement facilitated the correction of misconceptions and the transfer of knowledge from short-term to long-term memory (Pentucci et al., 2025; Vo et al., 2025). The highest gain observed in the indicator "applying concepts to problem solving" (from 58% to 89%) suggests that the reflection stage was particularly effective in enhancing students' ability to transfer knowledge to novel contexts, a key indicator of deep conceptual understanding.

3.2.2 Comparative Analysis with Previous Studies

To contextualize the findings within the broader landscape of chemistry education research, Table 11 presents a comparative analysis of the ALLR approach against other instructional models for teaching solution chemistry concepts.

Table 11. Comparative Analysis of the ALLR Approach with Previous Studies

Study	Instructional Approach	Topic	Sample	Key Findings	Effect Size	Limitations
Current Study	ALLR (Activity-based–Lesson–Learn–Reflection)	General chemistry	29 undergraduate students	Significant improvement in conceptual understanding (pretest 52.93 → posttest 80.52); N-Gain = 0.59 (moderate)	Cohen's d = 3.09 (large)	Pre-experimental design; no control group; small sample size
Raman et al. (2024).	Problem-Based Learning (PBL)	General chemistry	Systematic review of 25 studies	Enhanced problem-solving skills; improved critical thinking	Various (small to large)	Lack of structured reflection phase; variability in implementation
Spitha et al. (2024).	Simulation-based activity	Absorption phenomen n	45 undergraduate students	Improved submicroscopic reasoning; better connection between macroscopic and molecular levels	Partial η^2 = 0.24 (medium)	Focused only on visualizations; no explicit reflection component

Study	Instructional Approach	Topic	Sample	Key Findings	Effect Size	Limitations
Pitaloka et al. (2025).	Learning Cycle 5E with Interactive Simulator	Molecular shapes	32 undergraduate students	Improved understanding of molecular geometry; enhanced chemistry identity	Cohen's d = 1.82 (large)	Limited to visualization topics; no structured reflection phase
Pentucci et al. (2025).	Reflective learning intervention	General chemistry	18 undergraduate students	Enhanced self-reflection skills; improved metacognitive awareness	Qualitative only	Small sample size; no quantitative effect size reported
Ho et al. (2024).	CLEAR (contextualized storytelling)	General chemistry	120 undergraduate students	Improved connection between chemistry concepts and real-life contexts; enhanced self-directed learning	Cohen's d = 0.94 (large)	Focused on storytelling rather than hands-on activities; reflection is not explicitly structured.
Tella (2023)	Activity-based reflective strategies	Secondary chemistry	120 secondary students	Improved achievement in chemistry; activity-based reflection is more effective than explicit embedded reflection	$\eta^2 = 0.21$ (medium)	Secondary school context; may not generalize to the undergraduate level

The comparative analysis reveals several important insights. First, while various instructional approaches have demonstrated effectiveness in improving chemistry learning outcomes, the ALLR approach yielded the largest effect size (Cohen's d = 3.09) among the studies reviewed. This substantial effect size suggests that integrating four complementary stages (activity, lesson, learn, and reflection) yields a synergistic effect that exceeds the sum of its parts.

Second, the ALLR approach addresses a critical gap identified in previous research: the lack of structured reflection as an explicit component of the learning cycle. While studies such as Rahman. Et al. (2024) and Spitha et al. (2024) demonstrated the effectiveness of PBL and simulation-based activities. However, neither incorporated a dedicated reflection phase that enables students to examine their conceptual change metacognitively. Pentucci et al. (2025) focused exclusively on reflection, but their study lacked the hands-on activities and structured lessons that provide the experiential foundation for meaningful reflection.

Third, the ALLR approach uniquely integrates multiple theoretical perspectives (experiential learning, sociocultural theory, situated learning, and metacognitive theory) into a coherent pedagogical framework. This theoretical integration addresses the call by

Chooper & Stowe (2018) and Jegstad (2024) for more theoretically grounded instructional models that systematically guide students through knowledge construction.

3.2.3 Why ALLR is Superior to Other Approaches

The superiority of the ALLR approach stems from several distinctive features that address the limitations of existing instructional models. Unlike approaches that emphasize either active learning (e.g., PBL, PjBL) or reflection (e.g., reflective journals) in isolation, ALLR systematically integrates both components within a single learning cycle. The Activity-based stage provides concrete experiences that serve as anchors for subsequent learning, while the Reflection stage ensures that these experiences are critically examined and consolidated. This integration addresses the limitation identified by Brantley-Dias and Ertmer (2013) and Johnson and Wagner (that structured reflection remains underexplored in chemistry education research.

The Reflection stage distinguishes ALLR from other models by explicitly promoting metacognitive awareness. Students are guided to examine how their understanding has evolved, identify areas of confusion, and articulate their learning process. This metacognitive engagement is crucial for developing self-regulated learners who can monitor and adjust their own learning strategies (Vo et al., 2025). The substantial improvement in problem-solving ability (from 58% to 89%) suggests that this metacognitive component enhances students' capacity to apply concepts in novel contexts, a key indicator of transferable knowledge.

ALLR provides balanced scaffolding that gradually transfers responsibility from the instructor to the student (Widodo et al., 2019). The Lesson stage offers expert guidance to help students organize their observations, while the Learn stage encourages independent exploration and peer collaboration. This gradual release of responsibility, informed by Vygotsky's zone of proximal development, ensures that students are neither overwhelmed by excessive independence nor constrained by over-scaffolding.

The improvement across all four indicators of conceptual understanding demonstrates that ALLR addresses multiple dimensions of learning. The indicator "repeating concepts" improved from 52% to 85%, reflecting enhanced factual knowledge. The indicator "providing examples and non-examples" improved from 50% to 78%, indicating deeper conceptual discrimination. The indicator "using, utilizing, and selecting certain procedures" improved from 45% to 72%, demonstrating enhanced procedural knowledge. Most notably, the indicator "applying concepts to problem solving" improved from 58% to 89%, reflecting the development of transferable problem-solving skills. This comprehensive improvement contrasts with some previous studies that reported gains primarily in specific dimensions of understanding (Spitha et al., 2024; Tella, 2023).

ALLR is grounded in a coherent theoretical framework that integrates multiple learning theories. The Activity-based stage aligns with experiential learning theory (Kolb, 1984); the Lesson stage draws from sociocultural theory (Vygotsky, 1978); the Learn stage is informed by situated learning theory (Lave & Wenger, 1991); and the Reflection stage is grounded in metacognitive theory (Flavell, 1979). This theoretical integration ensures that each stage is pedagogically justified and mutually reinforcing, creating a learning cycle that is greater than the sum of its parts.

3.2.4 Limitations of the Study

While this study provides valuable insights into the effectiveness of the ALLR approach, several limitations must be acknowledged to contextualize the findings and guide future research. The pre-experimental one-group pretest-posttest design, while appropriate for an initial investigation, lacks a control group for comparison. This design cannot rule out the influence of extraneous variables such as history, maturation, or testing effects (Fraenkel et al., 2012). Although statistical analyses (normality testing, paired t-test, effect size calculation) strengthen the validity of the findings, the absence of a control group limits causal inferences. Future research should employ quasi-experimental or randomized controlled designs with comparison groups to establish causality more definitively.

The sample consisted of 29 first-semester Science Education students from a single Indonesian university, which limits the generalizability of the findings. The sample size, while adequate for a paired t-test analysis (Fraenkel et al., 2012), is relatively small and may not be representative of the broader population of undergraduate chemistry students. Additionally, the sample was drawn from a specific cultural and educational context; findings may not generalize to students in other countries or educational systems. Future research should include larger, more diverse samples from multiple institutions and cultural contexts to enhance external validity. Participants were selected using purposive sampling, which may introduce selection bias. Students enrolled in the Science Education program may have different motivational characteristics or prior knowledge than students in other programs (e.g., chemistry majors or engineering students). This limits the applicability of findings to other student populations. Future research should employ random sampling or include multiple student populations to enhance representativeness.

Conceptual understanding was measured using a 20-item multiple-choice test, which may not capture the full complexity of students' conceptual knowledge. While multiple-choice tests are efficient for large-scale assessment, they may not reveal the nuances of student thinking or the persistence of misconceptions (Salame & Casino, 2021b). Future research should complement quantitative measures with qualitative methods such as interviews, open-ended questions, or concept maps to gain deeper insights into students' conceptual understanding. The intervention was implemented over four meetings (400 minutes total), which may be insufficient to develop a deep conceptual understanding of complex solution chemistry topics. While significant gains were observed, longer interventions might yield larger effects and more sustained learning. Future research should investigate the optimal duration and intensity of ALLR implementation. This study measured conceptual understanding immediately after the intervention, but did not assess retention over time. Without delayed posttests, it is unclear whether the observed gains represent durable learning or short-term memory effects. Future research should include follow-up assessments (e.g., at 4-6 weeks post-intervention) to evaluate the sustainability of learning gains.

The study focused exclusively on solution chemistry concepts, limiting the applicability of findings to other chemistry topics. While the theoretical grounding of ALLR suggests it could be effective for other topics, empirical validation is needed. Future research should test the ALLR approach across multiple chemistry topics (e.g., chemical bonding, thermodynamics, kinetics) to establish its generalizability. The intervention was delivered by a single instructor who was also involved in the research. This may introduce instructor bias or confounding variables related to teaching style, enthusiasm, or expertise. Future research should involve multiple instructors and control for instructor effects through standardized protocols and training. The study focused on outcome measures (pretest-posttest scores) but did not collect process data on students' engagement with each ALLR stage. Without observations, student reflections, or think-aloud protocols, it is difficult to determine which specific components of ALLR contributed most to learning gains. Future research should collect rich qualitative data to illuminate the mechanisms through which ALLR enhances conceptual understanding.

4. CONCLUSION

This study investigated the effectiveness of the ALLR (Activity-based–Lesson–Learn–Reflection) approach in enhancing undergraduate students' conceptual understanding of solution concepts in general chemistry. The findings demonstrate that the ALLR approach significantly improved students' conceptual understanding, as evidenced by the increase in mean scores from 52.93 (pretest) to 80.52 (posttest), with a mean gain of 27.59 points. The statistical analysis confirmed significant improvement ($t(28) = 16.65$, $p < 0.001$), with a large effect size (Cohen's $d = 3.09$) and moderate N-Gain (0.59). All four indicators of conceptual understanding improved substantially, with the largest gain in applying concepts to problem-solving (from 58% to 89%).

This study makes several significant theoretical contributions. First, it provides empirical validation for integrating experiential and reflective learning within a single pedagogical framework. While previous research has established the effectiveness of activity-based learning and reflective practice separately, this study demonstrates that their systematic integration within the ALLR cycle yields synergistic effects that exceed the sum of their individual components. The large effect size ($d = 3.09$) suggests that the four-stage cycle creates a coherent learning experience in which each stage reinforces the others.

Second, the findings extend metacognitive theory by demonstrating how structured reflection enhances conceptual change. The substantial improvement in problem-solving ability supports Flavell's assertion that metacognitive engagement is crucial for deep understanding and knowledge transfer. The Reflection stage provides a systematic mechanism for students to examine their conceptual evolution, identify persistent misconceptions, and consolidate learning, addressing a critical gap in existing instructional models that lack explicit metacognitive components.

Third, this study contributes to understanding how multiple learning theories can be integrated into a coherent instructional framework. The ALLR approach successfully synthesizes experiential learning theory, sociocultural theory, situated learning theory, and metacognitive theory. Fourth, the findings contribute to conceptual change literature by demonstrating that ALLR effectively addresses persistent misconceptions in solution chemistry. The improvement across all indicators, particularly procedural knowledge (45% to 72%) and problem-solving (58% to 89%), suggests that combining hands-on activities, structured lessons, independent exploration, and critical reflection creates optimal conditions for conceptual restructuring.

For chemistry educators, the ALLR approach provides a structured yet flexible framework for lesson planning. The four-stage cycle offers clear guidance while allowing adaptation to specific topics and student needs. Educators can implement the Activity-based stage through experiments or simulations; the Lesson stage through targeted explanations connecting concrete experiences to formal theory; the Learn stage through collaborative problem-solving; and the Reflection stage through guided prompts that develop metacognitive awareness. The significant improvement in problem-solving ability suggests educators should prioritize integrating reflection into teaching practice, particularly for abstract topics where students struggle to connect macroscopic observations with submicroscopic explanations. For curriculum designers, the ALLR approach offers a model for structuring learning experiences across courses. The cycle can be applied to individual lessons, units, or entire semesters, providing coherence and progression. Curriculum developers should allocate sufficient time for each stage, particularly Reflection, and ensure learning objectives, activities, and assessments align with multiple dimensions of conceptual understanding—factual knowledge, conceptual discrimination, procedural application, and problem-solving transfer.

For teacher professional development, the findings highlight the need for programs that equip teachers to implement structured learning cycles. Teachers need training to facilitate hands-on activities, provide scaffolded explanations, design meaningful independent learning tasks, and guide productive reflection. Understanding the learning theories underpinning each stage can help teachers make informed pedagogical decisions. In educational technology, the ALLR approach can be enhanced by integrating virtual simulations, digital laboratories, online discussion forums, and learning management systems. Technology-enhanced implementation could potentially reach larger and more diverse student populations.

Several limitations suggest important directions for future research. Future research should: (1) employ quasi-experimental or randomized controlled designs with comparison groups to establish causality more definitively; (2) include larger, more diverse samples from multiple institutions, disciplines, and cultural contexts to enhance external validity; (3) test ALLR across multiple chemistry topics and other science disciplines to establish generalizability; (4) investigate optimal intervention duration and intensity, including longitudinal studies with delayed posttests to assess learning retention; (5) investigate student-level factors (prior knowledge, motivation, metacognitive ability) that moderate ALLR effectiveness; and (6) explore technology integration, teacher factors affecting implementation fidelity, and cost-effectiveness analyses comparing ALLR with traditional instruction.

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