Jurnal Ilmu Pendidikan (JIP)
Vol. 32, Issue 1, June 2026, pp. 1-9

ISSN: 0215-9643 e-ISSN: 2442-8655

Diagnosing Misconceptions in SN1 and SN2 Mechanisms Using a Five-Tier Diagnostic Test (FTDAT): Implications for Curriculum Improvement

Najah Baroud [1,*], Rania Alrwesse [2], Abtisam Aljarmi [3], Mowafg Masuwd [4]

University of Zawia, PO Box 16418, Zawia, Libya
[1]*n.baroud@zu.edu.ly**; [2]*r.rowesse@zu.edu.ly* ; [3]*ab.aljarmi@zu.edu.ly* ; [4]*masuwd@zu.edu.ly*
* *corresponding author*

ARTICLE INFO

Article history
Received Nov 22, 2025
Revised Jan 15, 2026
Accepted Feb 19, 2026

Keywords
SN1; SN2; nucleophilic substitution
Misconceptions
Five-tier diagnostic test (FTDAT);
diagram-supported instruction (DSC2I);
Organic chemistry education

ABSTRACT

This study diagnosed undergraduate students' misconceptions about nucleophilic substitution mechanisms and evaluated a diagnostic-informed teaching intervention. The scope focused on SN1 (unimolecular nucleophilic substitution) and SN2 (bimolecular nucleophilic substitution), emphasizing substrate effects, solvent effects, nucleophile role, and reaction energy profiles. Using a one-group pretest–posttest quasi-experimental design, 30 third-year chemistry students completed a Five-Tier Diagnostic Test (FTDAT) in the diagnostic phase. The FTDAT measured answer choice, justification, confidence, and reported knowledge sources. Pretest results indicated limited conceptual mastery, with scientific understanding observed in 34.5% of item responses (80/232), alongside substantial false-positive understanding and misconception patterns. The intervention applied Diagram-Supported Conceptual Contrast Instruction (DSC2I) using mechanistic visualization, supported by guided practice and digital learning tools. Post-instruction understanding was assessed using a teacher-made open-ended test aligned with the same conceptual indicators. Results showed marked improvement: the mean score increased from 8.6 to 17.4 out of 20, with a normalized gain of g = 0.61 and a large effect size (Cohen's d = 1.42). These findings support the value of five-tier diagnosis to guide targeted instruction for improving mechanistic reasoning in organic chemistry.

I. Introduction

High-quality learning in chemistry depends on supporting students in constructing scientifically accurate and conceptually coherent understanding. In organic chemistry in particular, this process is often challenging because students must integrate abstract theoretical ideas with multiple levels of chemical representation, including symbolic notation, structural formulas, reaction mechanisms, and particulate-level explanations. Learners are required not only to interpret symbols and equations but also to translate among macroscopic observations, submicroscopic processes, and symbolic representations. This representational complexity increases cognitive demand and may hinder deep conceptual understanding.

Moreover, many organic chemistry topics involve concepts that appear structurally similar yet operate through fundamentally different mechanisms. For example, reaction types may share comparable reactants or products but differ in reaction pathways, intermediates, or kinetic characteristics. When instruction does not explicitly highlight these distinctions, students may overgeneralize surface features and develop inaccurate mental models. Over time, such misunderstandings can solidify into misconceptions.

Misconceptions are defined as incorrect, incomplete, or alternative conceptions that are inconsistent with scientifically accepted explanations (Tümay, 2016; Kulgemeyer & Wittwer, 2023). These ideas may originate from everyday reasoning, prior informal learning experiences, oversimplified instruction, or misinterpretation of representations. Importantly, misconceptions are often robust and resistant to change, particularly when students hold them with high confidence. This confidence can create an illusion of understanding, making it difficult for both students and teachers to recognize conceptual gaps.

If misconceptions are not explicitly identified and addressed, they may persist and negatively affect subsequent learning, problem-solving, and knowledge transfer. Traditional assessment formats, such as multiple-choice tests, typically assess answer correctness but provide limited insight into students' reasoning processes or levels of certainty. As a result, correct responses may mask flawed reasoning (false positives), while incorrect

http://dx.doi.org/10.17977/um048v32i1p1-9

answers may not clearly distinguish between misconceptions and mere guessing.

To overcome these limitations, diagnostic assessment approaches have been developed to probe deeper into students' conceptual structures. Diagnostic instruments are designed not only to evaluate answer accuracy but also to uncover underlying reasoning patterns and levels of confidence. Such assessments enable educators to differentiate between genuine scientific understanding, partial understanding, and firmly held misconceptions, thereby supporting more targeted and responsive instructional decisions.

One recent and increasingly adopted approach is the Five-Tier Diagnostic Test. This instrument extends traditional multi-tier formats by requiring students to (a) select an answer, (b) provide justification, (c) indicate confidence level, and (d) identify the possible source of their knowledge, among other diagnostic elements (Jumaera et al., 2024). By integrating cognitive and metacognitive dimensions, the five-tier structure provides a more comprehensive profile of students' conceptual status. Teachers can therefore distinguish between correct answers supported by sound reasoning and those driven by guessing, incomplete logic, or alternative conceptions.

Due to its diagnostic precision, the Five-Tier Diagnostic Test has gained increasing attention in science and chemistry education research. Recent systematic reviews highlight its effectiveness in identifying misconceptions, mapping patterns of conceptual change, and informing instructional improvement and curriculum planning (Damsi & Suyanto, 2023; Novita et al., 2025). Consequently, integrating five-tier diagnostic instruments represents a promising strategy for enhancing evidence-based teaching practices and promoting deeper, more sustainable conceptual understanding in chemistry learning.

In organic chemistry, nucleophilic substitution reactions, particularly SN1 (unimolecular nucleophilic substitution) and SN2 (bimolecular nucleophilic substitution), remain among the most conceptually challenging topics for students. Learners frequently struggle to differentiate the two mechanisms, often confusing their characteristic steps, misapplying rules for mechanism selection, or misunderstanding the influence of solvents and substrates on reaction pathways. These difficulties persist even after formal instruction, suggesting that some students rely on rote memorization of the labels "SN1" and "SN2" without grasping the sequential processes or the underlying chemical principles (Fitriah & Pratimi, 2025). Recent research further highlights widespread confusion when students attempt to distinguish between the two mechanisms and connect reaction conditions to the appropriate mechanistic steps (Hunter, Groenenboom, Farheen, & Becker, 2025; Nartey, Koranteng, Oppong, & Hanson, 2024). Such misconceptions hinder students' ability to explain reaction outcomes and apply mechanistic reasoning to novel contexts, thereby limiting their capacity for higher-order chemical thinking (Pahriah, Sudatha, Suartama, & Santosa, 2025).

To reduce persistent learning difficulties in organic chemistry, assessment practices should extend beyond simply determining whether an answer is correct or incorrect. Multi-tier diagnostic tests provide richer insights because they require students not only to select an answer but also to explain their reasoning and indicate their confidence level. This layered approach enables teachers to distinguish between students who arrive at the correct answer by guessing and those who provide a correct response but rely on flawed reasoning. In doing so, the instrument reveals whether students genuinely understand the underlying mechanism. Moreover, these diagnostic tools highlight misconceptions that students hold with high confidence, signaling areas that demand greater instructional attention. Evidence from recent studies suggests that using diagnostic data can guide more targeted teaching strategies, strengthen the alignment between classroom activities and assessment practices, and inform curriculum improvements for topics that are consistently challenging in organic chemistry (Febliza, 2024; Habiddin & Page, 2023). Consequently, diagnosing misconceptions in substitution reactions such as SN1 and SN2 is essential for refining curriculum design and fostering stronger learning outcomes in organic chemistry (Nurdiyanti, Supahar, Ulfa, & Rudin, 2025).

This study is designed to identify third-year chemistry students' misconceptions about the SN1 and SN2 reaction mechanisms using a Five-Tier Diagnostic Test (FTDAT). The diagnostic framework focuses on critical mechanistic dimensions, including substrate effects, solvent effects, the role of the nucleophile, and reaction energy profiles. A second aim is to determine whether instruction informed by these diagnostic results leads to measurable improvements in students' mechanistic understanding following targeted teaching interventions. Attention is given to learning transitions, such as shifts from false-positive responses to scientifically accurate conceptions, to evaluate whether post-instruction gains reflect genuine conceptual change rather than guessing or superficial success. The anticipated findings are expected to contribute to more focused instructional practices, stronger alignment between assessment and classroom activities, and curriculum refinements for topics that remain persistently challenging in organic chemistry.

II. Method

A. Research Design and Procedure

This study used a diagnostic quasi-experimental design within a sequential diagnostic–intervention framework to examine students' conceptual understanding of nucleophilic substitution mechanisms: SN1 and SN2. The study first administered a Five-Tier Diagnostic Test (FTDAT) to diagnose misconceptions by combining answer selection, confidence in the answer, reasoning/justification, confidence in the reasoning, and reported source of knowledge (Jumaera, Blessing, & Rukondo, 2024). The study then designed and implemented a targeted instructional intervention based on the diagnostic profile and evaluated its impact through a teacher-made post-instruction assessment administered in the regular classroom context, thereby preserving ecological validity. Educational specialists in chemistry teaching reviewed the post-instruction test items to ensure content validity and confirm their suitability for use in educational research. Recent studies support the use of five-tier diagnostic instruments to reveal conceptual difficulties and inform instructional intervention in science education (Ma et al., 2025).

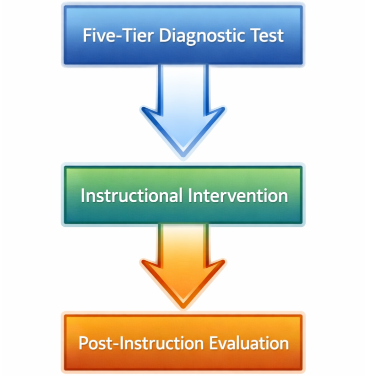

Fig. 1. Summary of the research process

B. Participants

The study involved 30 third-year undergraduate chemistry students enrolled in an organic chemistry course, all of whom had prior formal instruction in nucleophilic substitution reactions (SN1 and SN2), ensuring a shared foundational background. Purposive sampling was employed to select participants relevant to the research objectives, specifically students with documented conceptual difficulties in reaction mechanisms. Although the sample size was modest (N = 30), it is consistent with diagnostic-based classroom studies in chemistry education that emphasize in-depth analysis of students' conceptual understanding rather than broad statistical generalization. The same cohort participated in all stages of the study, including the Five-Tier Diagnostic Test, the diagnostic-informed instructional intervention, and the post-instruction assessment. This one-group pretest–posttest design enabled close tracking of conceptual change within a single cohort while minimizing instructional and contextual variability, in line with established methodological recommendations for diagnostic and conceptual change research (Köpeczi-Bócz, 2025).

C. Diagnostic Instrument

This study employed a Five-Tier Diagnostic Test (FTDAT) to evaluate students' conceptual understanding of SN1 and SN2 nucleophilic substitution mechanisms during the diagnostic phase. Each item integrated five components: (a) a conceptual multiple-choice question, (b) confidence in the selected option, (c) a written justification, (d) confidence in the justification, and (e) the reported source of knowledge. This multi-layered structure enhanced diagnostic validity by distinguishing genuine misconceptions from random guessing. The instrument was designed in two complementary formats: Conceptual and Reasoning-Based Questions (CRPQ), which required students to articulate mechanistic factors, and Mechanism Identification Questions (MIQ), which demanded accurate classification of SN1 versus SN2 based on structural and contextual cues. Such a design reflects the emphasis in chemistry education research on mechanistic reasoning as a central learning outcome in organic chemistry (Stowe & Cooper, 2020). To ensure consistency and facilitate data management, the FTDAT was administered via Google Forms, enabling standardized delivery and streamlined export for subsequent analysis.

D. Data Analysis (Diagnostic Phase)

The study analyzed students' responses using primarily descriptive statistics, including frequencies and percentages, to describe overall understanding and the distribution of misconception patterns. First, the analysis identified items with the highest error rates and the most frequent misconception themes related to key SN1 and SN2 mechanistic ideas. Next, each diagnostic response was interpreted using three indicators: correctness of the answer, quality of the written justification, and confidence ratings. This integrated approach helps distinguish scientific understanding from guessing and from high-confidence misconceptions that remain stable in students' thinking (Kaltakci-Gurel et al., 2015). Based on these indicators, each response was classified into five categories: Scientific understanding (S), Partial understanding (PU), False positive (FP), Misconception (MC), and Guessing (G). The same coding scheme was applied across items to support consistent interpretation and to detect hidden problems such as false positives and high-confidence misconceptions, which studies on substitution mechanisms also report as common learning difficulties (Nartey et al., 2024). To evaluate improvement after the intervention, the study summarized performance on the diagnostic test and the teacher-made post-instruction test using gain indices and effect-size statistics and examined transition patterns (FP → S) as evidence of conceptual change. The final diagnostic profile informed later teaching and curriculum redesign by linking specific weaknesses to targeted instructional actions (Rokhim et al., 2024).

E. *Instructional Intervention*

Guided by the diagnostic analysis, the study revised selected curriculum elements to address the most prevalent misconceptions and conceptual difficulties identified during the diagnostic phase. Based on the diagnostic profile, the study implemented a redesigned instructional approach for teaching SN1 and SN2 nucleophilic substitution mechanisms, with explicit focus on the conceptual weaknesses revealed by the Five-Tier Diagnostic Test (FTDAT). The intervention integrated evidence-based teaching strategies, most notably Diagram-Supported Conceptual Contrast Instruction (DSC2I). It emphasized direct comparison between SN1 and SN2 mechanisms to support mechanistic reasoning and improve conceptual differentiation. To increase student engagement and motivation, the intervention also incorporated gamification strategies (Delgado Meza et al., 2022; Wong, 2023). In addition, the instructional design used AI-supported visualization tools, including a Unity-based application and ChemSketch, to dynamically represent reaction pathways, intermediates, and transition states. Figure 2 shows that visualization-rich and interactive learning resources have been reported to support understanding and performance in challenging organic reaction mechanisms by making mechanistic processes more explicit and accessible than text-only explanations (Schweiker, Griggs, & Levonis, 2020).

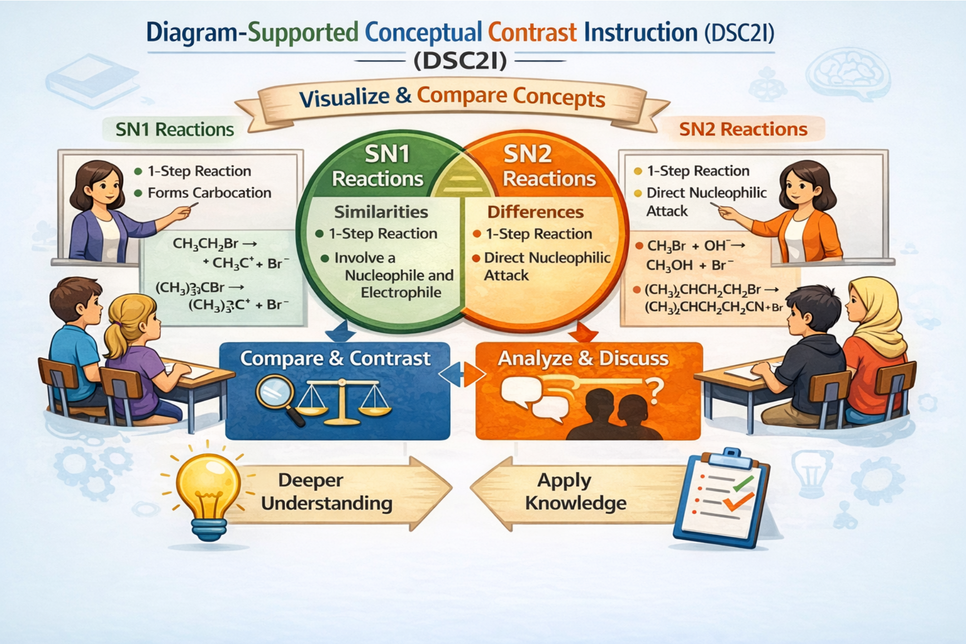

Fig. 2. Diagram-Supported Conceptual Contrast Instruction (DSC2I)

F. *Post-Instruction Evaluation*

Upon completion of the instructional intervention, students' conceptual understanding was re-evaluated using a teacher-made post-test aligned with the conceptual targets established during the diagnostic phase. The post-test measured learning gains in SN1 and SN2 mechanisms and evaluated the effect of the revised curriculum and teaching strategies. It comprised five open-ended, concept-focused questions developed from the diagnostic indicators of the Five-Tier Diagnostic Test (FTDAT). Unlike the diagnostic instrument, the post-test required students to construct explanations rather than select predefined options, thereby encouraging explicit mechanistic reasoning and the integration of core principles. To support content validity, each question was mapped to a specific conceptual indicator representing a key dimension of understanding nucleophilic substitution mechanisms (Table 1). This mapping ensured systematic coverage of major mechanistic domains, including substrate effects, energy profiles, solvent effects, leaving group ability, and nucleophile role, and enabled a structured evaluation of conceptual change after instruction.

Table 1. Conceptual Indicators and Alignment of Post-Test Questions

Question No.	**Question Focus**	**Conceptual Indicator Assessed**	**Mechanistic Dimension**
Q1	Substrate structure	Understanding the effect of substrate structure on reaction mechanism selection	Carbocation stability and steric effects
Q2	Energy profile comparison	Understanding reaction energy diagrams and mechanistic steps	Stepwise vs. concerted mechanisms

Question No.	Question Focus	Conceptual Indicator Assessed	Mechanistic Dimension
Q3	Solvent effects	Understanding the role of solvent polarity and proticity	Stabilization of intermediates and transition states
Q4	Leaving group characteristics	Understanding leaving group ability and its mechanistic implications	Bond cleavage and activation energy
Q5	Role of nucleophile strength	Understanding the differential role of nucleophile in SN1 and SN2	Rate-determining step involvement

G. *Data Analysis (Evaluation Phase)*

To evaluate conceptual change after the intervention, the analysis used descriptive statistics and learning-gain metrics based on students' post-test responses on SN1 and SN2 mechanisms. Students' open-ended responses were scored using an analytical rubric aligned with predefined conceptual indicators, which supported consistent and transparent evaluation. The analysis summarized performance using means, standard deviations, percentages, and mastery levels for each conceptual indicator and for the overall post-test. To evaluate the effectiveness of the instructional intervention, post-test performance was compared with pre-instruction outcomes from the Five-Tier Diagnostic Test (FTDAT) at the level of shared conceptual targets. The analysis calculated normalized gain (Hake's g) to estimate the magnitude of improvement and used Cohen's d to describe the practical significance of the observed learning gains. In addition, the study triangulated the findings by examining the alignment among diagnostic results, post-test performance, and students' scores on the course summative assessment, with an emphasis on mechanistic reasoning. This combined analytic approach provided converging evidence regarding conceptual change following the diagnostic-informed intervention (Lakens, 2022).

III. Results and Discussion

This section presents a comprehensive analysis of the findings derived from the Five-Tier Diagnostic Test and the subsequent post-instruction assessment. The results are systematically organized to provide a clear and coherent interpretation of students' conceptual development throughout the instructional process. Specifically, the analysis aims to: (i) characterize students' initial conceptual profiles prior to intervention, (ii) identify and categorize prevalent misconceptions and alternative conceptions, (iii) evaluate post-test performance and measure learning gains after the instructional treatment, and (iv) analyze patterns of conceptual transition following the diagnostic-informed instructional intervention.

The Five-Tier Diagnostic Test enabled a multidimensional examination of students' understanding by integrating answer accuracy, justification quality, and confidence levels. This structure enabled more precise differentiation among genuine scientific understanding, partial understanding, false positives, misconceptions, and guessing. Consequently, the findings not only reflect the correctness of responses but also reveal the depth, stability, and certainty of students' conceptual knowledge.

To ensure analytical clarity, the results are presented in sequential stages, beginning with students' baseline conceptual conditions before the intervention and progressing toward post-instruction outcomes. This structure facilitates a direct comparison between pre- and post-diagnostic data, highlighting areas of conceptual reinforcement, persistence of misconceptions, and shifts toward scientifically accurate understanding.

A. *Pre–Diagnostic Findings*

The pre-diagnostic results provide an overview of students' initial conceptual profiles before receiving the diagnostic-informed instructional intervention. These findings serve as a baseline for identifying dominant conceptual categories and determining the extent of misconceptions present at the outset. The distribution of responses across diagnostic categories reveals the relative proportions of students demonstrating scientific understanding, partial understanding, false-positive understanding, misconceptions, and guessing.

Analysis of the pre-test data indicates that while some students demonstrated correct responses with sound scientific justification, a considerable number exhibited incomplete reasoning, overconfidence in incorrect explanations, or strong adherence to misconceptions. The presence of high-confidence incorrect responses is particularly noteworthy, as it suggests deeply rooted alternative conceptions that require targeted conceptual change strategies.

Overall, the pre-diagnostic findings underscore the need to implement structured, conceptually focused instructional strategies. These baseline results function as a critical reference point for evaluating the effectiveness of the subsequent intervention and for tracing patterns of conceptual change across instructional phases:

B. *Pre-Diagnostic Conceptual Profile*

Analysis of the Five-Tier Diagnostic Test revealed substantial conceptual difficulties among students regarding SN1 and SN2 nucleophilic substitution mechanisms. As summarized in Table 1, only 16.7% of students demonstrated scientific understanding characterized by correct answers, coherent reasoning, and high confidence. In contrast, a large proportion of responses (43.3%) fell into the high-confidence misconceptions category, indicating that many students held incorrect ideas with strong confidence rather than mere uncertainty or guessing.

This pattern suggests that students' difficulties were rooted in stable alternative conceptions rather than insufficient exposure to content. Such findings align with previous research indicating that misconceptions in organic chemistry are often reinforced by confidence and thus resistant to traditional instructional approaches.

Table 2. Distribution of Diagnostic Categories (Pre-Diagnostic Test, N = 232 responses)

Category	Definition (Full Terms)	Frequency	Percentage (%)
S (Scientific Understanding)	Correct answer + correct scientific justification + high confidence	80	34.5%
PU (Partial Understanding)	Correct answer + incomplete/partially correct justification (confidence may vary)	74	31.9%
FP (False Positive Understanding)	Correct answer + incorrect/weak justification + high confidence	20	8.6%
MC (Misconception)	Incorrect answer + incorrect justification + high confidence	24	10.3%
G (Guessing)	Incorrect answer + weak/absent justification + low confidence	34	14.7%

Table 2 shows that scientific understanding formed about one-third of responses (34.5%). Partial understanding also appeared frequently (31.9%). Importantly, the test detected false positives (8.6%), where students selected the correct option but failed to justify it with sound reasoning. The results also show a meaningful share of confident misconceptions (10.3%), which suggests stable incorrect ideas rather than simple uncertainty.

C. *Prevalent Misconceptions in SN1 and SN2 Mechanisms*

Further analysis of the diagnostic pretest responses revealed consistent misconceptions across the major mechanistic dimensions of SN1 and SN2 reactions (Table 2). Percentages indicate the proportion of students (N = 30) demonstrating each misconception category. The highest misconception prevalence appeared in the nucleophile role (47%), where many students assumed that nucleophile strength controls the SN1 rate, although the SN1 rate is primarily determined by the ionization (carbocation-forming) step. Substantial misunderstanding also emerged in interpreting energy profiles (45%): many students treated activation-energy peaks as indicators of general "difficulty" rather than using the diagram to distinguish mechanistic steps (stepwise SN1 versus concerted SN2). Misconceptions about solvent effects (41%) were also common, with students often believing that solvent choice influences SN1 and SN2 reactions equally. Finally, misconceptions about substrate structure (38%) appeared when students selected SN1 for primary substrates and overlooked the roles of carbocation stability and steric effects. Overall, these patterns suggest difficulty integrating structure, kinetics, and energetics into causal mechanistic explanations, indicating a need for instruction that emphasizes mechanistic reasoning and electron-flow logic rather than mechanism labeling alone.

Table 3. Prevalent Misconceptions Identified for SN1 and SN2 Mechanisms

Conceptual Aspect	Misconception Description	%
Substrate Effect	Assuming primary substrates favor SN1	38%
Energy Profile	Interpreting peaks as difficulty, not mechanistic steps	45%
Solvent Role	Belief that solvent affects SN1 and SN2 equally	41%
Nucleophile Role	Assuming nucleophile strength controls SN1 rate	47%

Percentages in Table 3 represent the proportion of students who showed each misconception at least once

D. *Post-Test Performance and Learning Gains*

The post-test results indicate clear improvement in students' conceptual understanding across all five conceptual indicators (Table 4). Overall performance was strong, with most indicators falling within the high mastery range. Students demonstrated the highest mastery in leaving group ability and substrate structure, and they also performed well in solvent effects and energy-diagram interpretation. However, the nucleophile role remained the most challenging indicator. This pattern is consistent with the diagnostic phase, in which nucleophile-related misconceptions were the most prevalent (Table 3). Taken together, the findings suggest that the intervention strengthened mechanistic understanding across multiple domains, while the nucleophile concept may require additional emphasis and reinforcement in subsequent instruction.

Table 4. Post-Test Performance by Conceptual Indicators

Conceptual Indicator	Mean Score (20)	SD	Mastery Level
Substrate Structure	17.9	1.4	High
Energy Diagram	16.8	1.9	High
Solvent Effect	17.5	1.6	High
Leaving Group	18.2	1.2	High
Nucleophile Role	16.4	2.1	Moderate–High

A pre–post comparison showed substantial improvement in overall performance (Table 5). The mean score increased from 8.6 (SD = 3.1) on the FTDAT pre-test to 17.4 (SD = 1.9) on the teacher-made post-test. The reduction in standard deviation suggests that students' scores became more clustered at higher levels after the intervention, indicating greater understanding that is consistent across the cohort. The normalized gain (Hake's g = 0.61) reflects moderate-to-high improvement, and the effect size (Cohen's d = 1.42) indicates a large instructional impact. Taken together, these findings suggest that the diagnostic-informed teaching model strengthened students' mechanistic understanding of SN1 and SN2, not only by raising scores but also by improving the quality and consistency of learning outcomes.

Table 5. Pre–Post Comparison and Learning Gain

Measure	Pre-Test	Post-Test
Mean	8.6	17.4
Standard Deviation	3.1	1.9
Normalized Gain (g)	—	0.61
Effect Size (Cohen's d)	—	1.42

Table 5 reports student-level total scores (N = 30) on the FTDAT pre-test and the teacher-made post-test (both scored out of 20). Each student's pre-test total score (max = 20) was calculated by summing item scores based on the diagnostic coding rubric, and each student's post-test total score (max = 20) was calculated by summing rubric scores across the five open-ended questions. Percentages in the diagnostic results are based on 232 coded item responses from the FTDAT.

This study indicates that many undergraduate students experience substantial difficulty with SN1 and SN2 nucleophilic substitution mechanisms. These difficulties are not limited to isolated factual mistakes; rather, a considerable proportion of students appear to hold stable alternative conceptions, often with high confidence. The most persistent problems concerned interpreting energy profiles, explaining solvent effects, and understanding the role of the nucleophile. This pattern aligns with previous work showing that students frequently struggle to build coherent mechanistic explanations in organic chemistry, particularly when multiple representations and conditional factors must be integrated (Reyes, 2025; Mayer & Ottosson, 2025).

The diagnostic-informed teaching model was effective partly because it began with explicit diagnostic evidence. The study first identified dominant misconception themes and examined confidence patterns, then used these results to shape instruction around the specific conceptual weaknesses detected. As a result, teaching focused not only on presenting correct information but also on helping students reconstruct explanations and replace incorrect causal reasoning with more scientifically grounded mechanistic thinking. The post-instruction results indicated a clear reduction in misconception patterns and a stronger level of conceptual mastery, suggesting improvement in understanding rather than superficial score gains.

The intervention also used a conceptual contrast between SN1 and SN2. Students directly compared both mechanisms, which helped them see how each pathway depends on different conditions and steps and encouraged reasoning rather than memorizing rules. The lessons also included work with energy profiles, which helped students connect reaction steps to intermediates, activation barriers, and the rate-determining step. These activities addressed an important gap observed during the diagnostic phase: many students could demonstrate "what happens" in a mechanism but struggled to explain "why it happens" using electron flow and causal mechanistic logic. This pattern aligns with previous findings on gaps in mechanistic thinking and electron-pushing understanding (Nartey et al., 2024). Because the post-test required constructed explanations scored with an analytic rubric, the post-instruction improvement reflects gains in mechanistic reasoning rather than just recognition of correct options.

The diagnostic results also revealed a notable proportion of false positives, in which students selected correct options but provided weak or incorrect reasoning. This finding highlights the value of the five-tier diagnostic approach for uncovering hidden conceptual problems that traditional assessments may not detect. Such false-positive patterns can give students a misleading sense of mastery and may delay conceptual development if instruction focuses only on correct answers. Therefore, diagnostic assessment can play an important role in guiding targeted teaching that addresses both answer accuracy and the reasoning behind students' choices.

V. Conclusion

The findings of this study indicate that many undergraduate students face persistent conceptual difficulties with SN1 and SN2 nucleophilic substitution mechanisms, often supported by high-confidence misconceptions. The most frequent misconceptions involved the role of the nucleophile, interpretation of energy profiles, solvent effects, and substrate effects. After implementing the diagnostic-informed DSC2I teaching approach, students demonstrated clear improvement, as reflected in strong learning gains and evidence of conceptual development beyond simple score increases. However, misconceptions about the nucleophile remained the most challenging, indicating a need for more focused practice and a clearer step-by-step explanation of how nucleophile strength and reaction conditions relate differently to SN1 and SN2 rates and mechanisms. In summary, the study identified key misconceptions and demonstrated how diagnostic instruction can strengthen students' conceptual understanding of reaction mechanisms. The findings also have practical implications for curriculum design, supporting the DSC2I model as an effective instructional package when combined with a five-tier diagnostic assessment in organic chemistry. Future research should use larger samples, include a control or comparison group, and incorporate delayed post-tests to examine retention. Applying the same diagnostic-informed approach to other mechanisms (E1/E2) is also recommended to test its broader applicability.

References

Aljarmi, A., Baroud, N., & Algub, S. (2025). The impact of integrating gamification into cooperative learning TPS on students' mastery of heterocyclic compound nomenclature. *Orbital: Jurnal Pendidikan Kimia, 9*(1), 29–42. https://doi.org/10.19109/ojpk.v9i1.27826

Damsi, M., & Suyanto, S. (2023). Systematic literature review: Multiple-tier diagnostic instruments in measuring student chemistry misconceptions. *Jurnal Penelitian Pendidikan IPA, 9*(5), 8–21. https://doi.org/10.29303/jppipa.v9i5.2600

Meza, J. A. D., Castro, M. L. C., & Vivas, R. V. J. (2022). The diagram as a mediator in collaborative learning: A conceptual review. *Learning, Culture and Social Interaction*, *35*, 100634. https://doi.org/10.1016/j.lcsi.2022.100634

Febliza, A. (2024). Development and validation of multi-tier diagnostic test instruments for chemistry misconceptions. *Journal of Innovative Science Education, 13*(3), 124–133. https://doi.org/10.15294/jise.v13i3.13578

Fitriah, L., & Pratimi, R. S. (2025). Evaluating the use of ChemTube3D to enhance students' conceptual understanding of nucleophilic substitution reactions. *Empiricism Journal, 6*(2), 535–542. https://doi.org/10.36312/ej.v6i2.2884

Habiddin, H., & Page, E. M. (2023). Uncovering students' genuine misconceptions: Evidence to inform the teaching of chemical kinetics. *Acta Chimica Slovenica, 70*(2). https://doi.org/10.17344/acsi.2022.7880

Hunter, K. H., Groenenboom, L. A., Farheen, A., & Becker, N. M. (2025). Student conceptualizations and predictions of substitution and elimination reactions: What are they seeing on the page? *Chemistry Education Research and Practice, 26*(1), 334–350. https://doi.org/10.1039/d4rp00204k

Jumaera, S., Blessing, O. T., & Rukondo, N. (2024). Optimizing student activities and learning outcomes through problem-solving models in stoichiometry material. *Journal of Chemical Learning Innovation, 1*(2), 39–44. https://doi.org/10.37251/jocli.v1i2.1147

Kaltakci-Gurel, D., Eryilmaz, A., & McDermott, L. C. (2015). A review and comparison of diagnostic instruments to identify students' misconceptions in science. *Eurasia Journal of Mathematics, Science and Technology Education, 11*(5), 989–1008. https://doi.org/10.12973/eurasia.2015.1369a

Köpeczi-Bócz, T. (2025). Cognitive-dissonance-based educational methodological innovation for a conceptual change to increase institutional confidence and learning motivation. *Education Sciences, 15*(3), 378. https://doi.org/10.3390/educsci15030378

Kulgemeyer, C., & Wittwer, J. (2023). Misconceptions in physics explainer videos and the illusion of understanding: An experimental study. *International Journal of Science and Mathematics Education, 21*(2), 417–437. https://doi.org/10.1007/s10763-022-10265-7

Lakens, D. (2022). Sample size justification. *Collabra: Psychology, 8*(1), 33267. https://doi.org/10.1525/collabra.33267

Ma, H., Liu, W., & Li, G. (2025). Development and application of a five-tier diagnostic test to assess misconceptions on respiration and photosynthesis among senior high school students in mainland China. *Research in Science Education, 55*, 1427–1452. https://doi.org/10.1007/s11165-025-10232-6

Mayer, P. J., & Ottosson, H. (2025). False identification of (anti)aromaticity in polycyclic molecules in ground and excited states through incorrect use of NICS. *Journal of Physical Organic Chemistry*. https://doi.org/10.1002/poc.70000

Nartey, E., Koranteng, E., Oppong, E. K., & Hanson, R. (2024). Analysis of undergraduate chemistry students' responses to substitution reaction mechanisms: A road to mastery. *Chemistry Teacher International, 6*(3), 231–240. https://doi.org/10.1515/cti-2023-0075

Novita, D., Muchlis, R., Yonata, B., Asih, F. E., & Artiono, R. (2025). Investigating the utility of a misconception detection application as an early detection tool based on the five-tier diagnostic test. *Journal of Chemistry Education Research*. https://doi.org/10.26740/jcer.v9n1.p45-51

Nurdiyanti, N., Supahar, S., Ulfa, S. M., & Rudin, I. (2025). Diagnostic test research trends in science education: A systematic review. *International Journal of Multicultural and Multireligious Understanding, 12*(5), 225–239. https://doi.org/10.18415/ijmmu.v12i5.6679

Pahriah, P., Sudatha, I. G. W., Suartama, I. K., & Santosa, M. H. (2025). Students' misconceptions in chemistry learning: A systematic literature review from 2015 to 2025. *Hydrogen: Jurnal Kependidikan Kimia, 13*(3), 510–529. https://doi.org/10.33394/hjkk.v13i3.15805

Reyes, R. L. (2025). Addressing common student errors and misconceptions in chemical stoichiometry: Insights for enhanced instruction in introductory general chemistry. *International Journal of Science, Mathematics & Technology Learning, 32*(2), 167–188. https://doi.org/10.18848/2327-7971/CGP/v32i02/167-188

Rokhim, D. A., Widarti, H. R., & Sutrisno, S. (2024). Five-tier instrument to identify students' misconceptions and representation: A systematic literature review. *Orbital: Electronic Journal of Chemistry, 15*(4), 202–207. https://doi.org/10.17807/orbital.v15i4.17709

Schweiker, S. S., Griggs, B. K., & Levonis, S. M. (2020). Engaging health students in learning organic chemistry reaction mechanisms using short and snappy lightboard videos. *Journal of Chemical Education, 97*(11), 3867–3871. https://doi.org/10.1021/acs.jchemed.0c00619

Schwenz, R. W. (2020). Safety education in the context of the ACS guidelines, "Undergraduate professional education in chemistry: ACS guidelines and evaluation procedures for bachelor's degree programs." *Journal of Chemical Education, 98*(1), 34–38. https://doi.org/10.1021/acs.jchemed.0c0018

Simanjuntak, B. R. N., Wiji, W., & Widhiyanti, T. (2025). Systematic literature review: A three-tier diagnostic test for identifying misconceptions in chemistry. *Jurnal Penelitian Pendidikan IPA, 11*(7), 37–47. https://doi.org/10.29303/jppipa.v11i7.11011

Stowe, R. L., Esselman, B. J., Ralph, V. R., Ellison, A. J., Martell, J. D., DeGlopper, K. S., & Schwarz, C. E. (2020). Impact of maintaining assessment emphasis on three-dimensional learning as organic chemistry moved online. *Journal of Chemical Education*, *97*(9), 2408-2420. https://doi.org/10.1021/acs.jchemed.0c0-0757

Tümay, H. (2016). Reconsidering learning difficulties and misconceptions in chemistry: Emergence in chemistry and its implications for chemical education. *Chemistry Education Research and Practice*. https://doi.org/-10.1039/C6RP00008H

Wong, M. H. I. (2023). Fostering conceptual understanding through computer-based animated schematic diagrams and cue contrast. *TESOL Quarterly, 57*(4), 1309–1338. https://doi.org/10.1002/tesq.3195