Jambura Journal of Educational Chemistry
Volume 8 Issue 2, Augsut 2026
p-ISSN: 2655-7606, e-ISSN: 2656-6427
Journal Homepage: http://ejurnal.ung.ac.id/index.php/jjec

Analysis of Thermochemistry Concept Understanding of Grade XI Students Based on the Consistency of Students' Answers Using the Parallel Three-Tier Diagnostic Test

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Article Info

Article history:
Received: 22-05-2026
Revised: 01-06-2026
Accepted: 02-06-2026
Available online: 01-08-2026

Keywords:
Concept Understanding; Thermochemistry; Misconception; Answer Consistency; Parallel Diagnostic Test

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Abstract

Thermochemistry is frequently regarded as difficult because students must connect observable heat phenomena, particle-level energy changes, and symbolic enthalpy calculations. This descriptive quantitative diagnostic study aimed to analyze grade XI students' thermochemistry conceptual understanding based on answer consistency using a parallel three-tier diagnostic test. Answer consistency was defined as the alignment of response patterns across parallel item pairs measuring the same concept in terms of answer accuracy, reasoning accuracy, and confidence level. The study involved 135 grade XI students at a senior high school in Gorontalo during the odd semester of the 2025/2026 academic year. The instrument consisted of 20 parallel three-tier multiple-choice items arranged into 10 equivalent pairs. Instrument quality was examined through expert validation and empirical testing using the Rasch model, with a Cronbach alpha of 0.68, person reliability of 0.69, item reliability of 0.90, person separation index of 1.49, and item separation index of 2.96. Data were analyzed by calculating paired-item consistency and classifying individual responses into sound conceptual understanding (correct answer, correct reason, confident), M1 (correct answer, incorrect reason, confident), M2 (incorrect answer, correct reason, confident), M3 (incorrect answer, incorrect reason, confident), and lack of conceptual understanding. Results showed that average answer consistency across parallel pairs was 29.48%, whereas inconsistency reached 70.52%. In individual-item classification, sound conceptual understanding averaged 51.19%, followed by M1 at 11.19%, M2 at 16.84%, M3 at 10.04%, and lack of conceptual understanding at 10.85%. These findings indicate that many students' thermochemistry understanding was not stable across equivalent contexts, especially in Hess law, calorimetry, and bond energy concepts.

How to Cite: Arkani, F., Sihaloho, M., Suleman, N., Laliyo, L. A. R., & Ischak, N. I. (2026). Analysis of Thermochemistry Concept Understanding of Grade XI Students Based on the Consistency of Students' Answers Using the Parallel Three-Tier Diagnostic Test. *Jambura J. Educ. Chem.*, *8*(2), 197-204. https://doi.org/10.37905/jjec.v8i2.39096

1. INTRODUCTION

Chemistry learning requires students to develop coherent conceptual understanding rather than merely memorizing terms, formulas, and algorithmic procedures. Thermochemistry is one of the core topics in senior high school chemistry because it explains the relationship between chemical reactions and heat changes. The topic includes the concepts of system and surroundings, exothermic and endothermic reactions, enthalpy change, standard enthalpy change, Hess law, calorimetry, and bond energy. These concepts are important because they support later understanding of reaction energetics, chemical equilibrium, and other advanced chemistry topics. However, thermochemistry is also considered difficult because students must interpret real phenomena, particle-level energy processes, and symbolic mathematical calculations simultaneously (Gusmilasari et al., 2020; Hidayat et al., 2024; Rosyidah et al., 2024).

Previous studies have consistently reported that students experience conceptual difficulties and misconceptions in thermochemistry, but these findings need to be understood as part of a broader problem of unstable conceptual understanding. Misconceptions often occur when students interpret exothermic reactions as reactions that require heat, consider negative enthalpy changes as heat absorption, fail to distinguish open, closed, and isolated systems, or use thermochemical equations without adjusting reaction direction and stoichiometric coefficients (Irfandi et al., 2022; Sihaloho et al., 2021; Widyaningsih & Aloysius, 2024). Difficulties are especially prominent in subtopics that require students to coordinate conceptual reasoning and mathematical procedures, such as Hess law, calorimetry, and bond energy (Rasyidah et al., 2024; Yanti et al., 2024). These difficulties suggest that students may appear to understand a concept in one problem context but fail to apply the same concept when the representation, numerical data, or wording changes. If such misconceptions and inconsistencies are not diagnosed early, they may persist and interfere with students' understanding of more complex chemistry concepts (Damsi & Suyanto, 2023; Yamtinah et al., 2019).

Diagnostic assessment is needed to distinguish students who have sound conceptual understanding from those who guess, memorize procedures, or hold strong misconceptions. A three-tier diagnostic test can identify students' answer choices, reasoning, and confidence level; therefore, it provides more precise information than ordinary multiple-choice tests (Elvia et al., 2020; Lestari et al., 2021; Maison et al., 2020). Nevertheless, many diagnostic studies classify students' understanding based on single items, so they do not fully show whether students can maintain the same conceptual reasoning across equivalent contexts. A correct response to one item may result from contextual clues, memorized formulas, or procedural substitution rather than transferable understanding. For that reason, a parallel test is useful because it employs equivalent item pairs to measure the same concept and compare students' response patterns (Kartowagiran et al., 2019; Openhotman et al., 2017).

The research gap addressed in this study is the limited use of parallel item-pair consistency in thermochemistry diagnostic assessment. The novelty of this study lies in combining the three-tier diagnostic format with parallel item pairs to analyze answer consistency on thermochemistry concepts. The parallel three-tier diagnostic test enables the researcher to identify not only the category of students' conceptual understanding but also whether that understanding is stable across equivalent questions. In this study, the terms sound conceptual understanding and lack of conceptual understanding are used to provide clearer academic terminology for students' diagnostic categories. Therefore, the research questions are: (1) how consistent are students' answers on thermochemistry concepts when measured using a parallel three-tier diagnostic test? and (2) how is students' thermochemistry conceptual understanding distributed across sound conceptual understanding, misconception patterns, and lack of conceptual understanding categories?.

2. METHOD

This study used a descriptive quantitative diagnostic approach. The research was conducted at a senior high school in Gorontalo Province during the odd semester of the 2025/2026 academic year. The specific school name was anonymized to protect institutional and participant confidentiality because the study reports students' conceptual difficulties and misconception patterns. The participants were 135 grade XI students who had completed instruction on thermochemistry and were present during data collection. The participant selection used an accessible-sample approach based on the class groups available at the research site, with inclusion criteria that students had studied thermochemistry, agreed to participate, and completed the diagnostic test. Institutional permission and participant consent were obtained before data collection, and students' responses were analyzed anonymously.

The instrument was a parallel three-tier diagnostic test consisting of 20 items arranged into 10 parallel item pairs. Each pair measured the same thermochemistry indicator but used a different context, wording, or data presentation. Each item consisted of three tiers: the first tier asked for the answer to a multiple-choice concept problem, the second tier asked for the reason supporting the answer, and the third tier asked for students' confidence. The confidence tier consisted of two options, namely "sure" and "not sure". The measured indicators included system and surroundings, thermochemical data, exothermic and endothermic reactions, heat and reaction stoichiometry, reaction type based on enthalpy change, standard enthalpy of formation, calorimetry, Hess law, average bond energy, and reaction enthalpy based on bond energy data.

The instrument was validated by three experts and obtained a construct validity score of 95%, indicating a very valid category. Empirical validity and reliability were analyzed using the Rasch model with Winstep version 3.73. Item-fit interpretation followed the Rasch criteria used in the thesis data analysis, including the evaluation of item fit and item discrimination through point-measure correlation. The empirical test indicated that all 20 items were fit and feasible for measuring students' thermochemistry conceptual understanding and answer consistency. The reliability analysis showed a Cronbach alpha of 0.68, person reliability of 0.69, item reliability of 0.90, person separation index of 1.49, and item separation index of 2.96. These results indicate that the instrument had adequate internal consistency and good item quality for diagnostic use; however, the relatively low person reliability and person separation index show that the grouping of students' ability should be interpreted cautiously (Fadhilah et al., 2024; Laliyo et al., 2022).

Data analysis was carried out in two stages. First, students' answers on each parallel item pair were compared to determine answer consistency. In this study, answer consistency was operationally defined as the alignment of students' response patterns across two parallel items measuring the same concept, especially in terms of answer accuracy, reasoning accuracy, and confidence level. A student was categorized as consistent when the response pattern on both parallel items was conceptually aligned, whereas a student was categorized as inconsistent when the response pattern differed across the item pair. This analysis used the parallel item pair as the unit of analysis.

Second, individual item responses were classified into five diagnostic categories: sound conceptual understanding (correct answer, correct reason, confident), M1 (correct answer, incorrect reason, confident), M2 (incorrect answer, correct reason, confident), M3 (incorrect answer, incorrect reason, confident), and lack of conceptual understanding (response patterns accompanied by uncertainty or weak conceptual support). The misconception labels were used as diagnostic indicators of inconsistent or problematic reasoning rather than as definitive claims about students' mental models. In particular, M2 was interpreted cautiously because an incorrect answer with a correct reason may also reflect calculation error, misreading, or item ambiguity. Percentages were calculated by dividing the number of students in each category by the total number of test participants and multiplying by 100%.

Table 1. Summary of instrument validation and reliability

Aspect	Result	Interpretation
Expert validation	95%	Very valid
Cronbach alpha	0.68	Adequate
Person reliability	0.69	Adequate
Item reliability	0.90	Good
Person separation index	1.49	Low
Item separation index	2.96	Adequate
Item fit	20 items fit	Feasible for data collection

Note. The instrument consisted of 20 items in 10 parallel pairs. The interpretation follows the criteria used in the thesis data analysis.

3. RESULT AND DISCUSSION

3.1. Result

The results are presented in two parts. The first part describes the consistency of students' answers across the 10 pairs of parallel thermochemistry items, while the second part describes the distribution of students' conceptual understanding categories based on the three-tier diagnostic criteria. The paired-item consistency analysis and the individual-item classification were treated as different units of analysis. Therefore, the average consistency score of 29.48% and the average sound conceptual understanding score of 51.19% should not be interpreted as contradictory, because the former refers to stability across parallel pairs and the latter refers to classification of individual item responses. Overall, the results indicate that many students could answer certain items correctly but could not consistently maintain the same conceptual reasoning when the concept was presented in another equivalent context.

Table 2. Student concept understanding based on the consistency of students' answers

No.	Indicator	Item pair	Correct item 1 (%)	Correct item 2 (%)	Consistent/ Inconsistent (%)
1	System and environment	1 and 11	58.52	53.33	**37.04 / 62.96**
2	Thermochemical data	2 and 12	54.81	34.07	**20.74 / 79.26**
3	Exothermic and endothermic reactions	3 and 13	56.03	42.96	**30.37 / 69.63**

https://doi.org/10.37905/jjec.v8i2.39096

No.	Indicator	Item pair	Correct item 1 (%)	Correct item 2 (%)	Consistent/ Inconsistent (%)
4	Heat and reaction stoichiometry	4 and 14	57.04	73.33	**49.63 / 50.37**
5	Reaction type based on ΔH	5 and 15	92.59	61.48	**55.56 / 44.44**
6	Standard enthalpy of formation	6 and 16	60.74	48.89	**33.33 / 66.67**
7	Calorimetry	7 and 17	56.03	29.63	**14.07 / 85.93**
8	Hess law	8 and 18	68.89	33.33	**28.15 / 71.85**
9	Average bond energy	9 and 19	42.22	39.26	**16.30 / 83.70**
10	Reaction enthalpy from bond energy	10 and 20	20.74	39.26	**9.63 / 90.37**
Average	-	-	**51.19**	-	**29.48 / 70.52**

Note. The item pairs measure the same indicator using different contexts. The average correct-answer percentage is shown in the first item column because it reflects the overall correct-answer average reported in the source thesis.

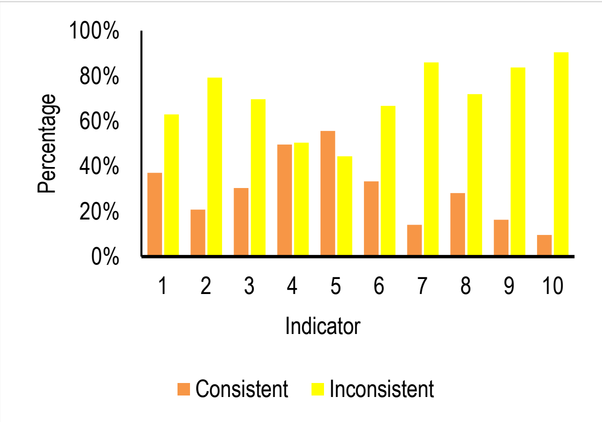

Figure 1. The percentage of students' consistency in understanding thermochemistry concepts

Table 3. Criteria for students' conceptual understanding of thermochemistry material

No.	Indicator	TK (%)	M1 (%)	M2 (%)	M3 (%)	TPK (%)
1	System and environment	55.93	7.78	22.23	12.97	1.11
2	Thermochemical data	44.44	4.07	27.41	10.74	13.35
3	Exothermic and endothermic reactions	49.63	5.56	27.78	7.04	10.01
4	Heat and reaction stoichiometry	65.19	12.97	2.96	5.93	12.96
5	Reaction type based on ΔH	77.04	7.41	1.48	7.04	7.03
6	Standard enthalpy of formation	54.82	4.82	6.30	15.56	18.53
7	Calorimetry	42.97	7.78	26.30	7.41	15.57
8	Hess law	51.11	27.04	3.33	8.52	10.01
9	Average bond energy	40.74	20.74	12.59	7.78	18.15
10	Reaction enthalpy from bond energy	30.00	13.71	13.33	24.45	18.52
Average	-	**51.19**	**11.19**	**16.84**	**10.04**	**10.85**

Note. TK = knowing concept; M1 = correct answer, incorrect reason, sure; M2 = incorrect answer, correct reason, sure; M3 = incorrect answer, incorrect reason, sure; TPK = not understanding concept.

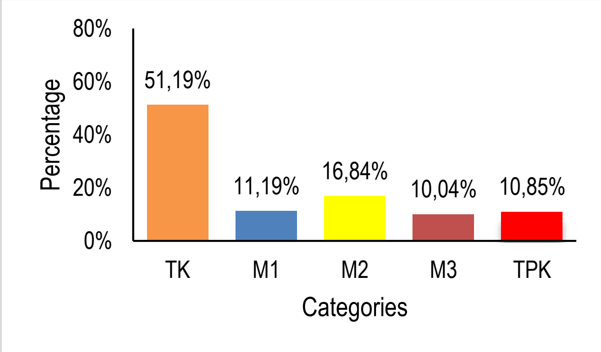

Figure 2. Average distribution of students' concept understanding categories.

As shown in Table 2 and Figure 1, the average consistency of students' answers was 29.48%, whereas the average inconsistency reached 70.52%. This means that most students could not consistently apply the same thermochemistry concept when the question was presented in a different context. The highest consistency occurred in the indicator of determining reaction type based on the sign of enthalpy change, with 55.56% consistency and 44.44% inconsistency. This indicator also had the highest sound conceptual understanding percentage, 77.04%, indicating that students were relatively more familiar with the relationship between negative enthalpy change and exothermic reactions. However, the consistency level was still far from optimal because almost half of the students changed their response pattern in the parallel item.

The lowest consistency was found in the indicator of analyzing reaction enthalpy using bond energy data. Only 9.63% of students were consistent, while 90.37% were inconsistent. Low consistency was also found in calorimetry (14.07% consistent), average bond energy (16.30% consistent), and determining enthalpy change from thermochemical data (20.74% consistent). These indicators require students to integrate conceptual understanding with mathematical operations, including identifying bonds broken and formed,

https://doi.org/10.37905/jjec.v8i2.39096

converting gas volume to mole, adjusting reaction coefficients, and reversing the sign of enthalpy when reaction direction changes. The very low consistency in these indicators suggests that some students may rely on algorithmic procedures without fully understanding the conceptual meaning of the steps they use.

Table 3 and Figure 2 show that the average percentage of students in the sound conceptual understanding category was 51.19%. However, this result should be interpreted carefully because answer consistency was much lower than the individual-item conceptual understanding percentage. This difference indicates that several students were able to answer certain items correctly but did not necessarily possess stable conceptual understanding across equivalent contexts. The misconception-related diagnostic patterns were also substantial: M1 was 11.19%, M2 was 16.84%, and M3 was 10.04%. The lack of conceptual understanding category reached 10.85%. The largest sound conceptual understanding percentage was found in determining reaction type based on enthalpy change (77.04%), while the lowest was found in analyzing reaction enthalpy using bond energy data (30.00%).

Misconception patterns varied across indicators. For system and surroundings, students confused closed systems and isolated systems because they classified systems based on the physical form of containers rather than energy and mass transfer. In exothermic and endothermic concepts, students often associated “hot” phenomena directly with endothermic processes or interpreted negative enthalpy change as energy absorption. In Hess law, several students added all enthalpy values without first adjusting the direction of equations and coefficients. In calorimetry, students had difficulty linking temperature increase, heat released by the reaction, heat absorbed by the solution, and the negative sign of enthalpy change. In bond energy, students often failed to distinguish bonds broken from bonds formed and used total enthalpy values without considering the number of bonds involved. These examples show that the diagnostic categories should be read together with item context and reasoning patterns, not only as numerical labels.

3.2. Discussion

The low answer consistency indicates that students’ thermochemistry understanding was still unstable. A student who correctly answers one item does not automatically demonstrate robust conceptual understanding if the same concept cannot be applied to a parallel item. This finding supports the need for consistency analysis in diagnostic testing because single-item correctness may overestimate students’ conceptual stability. The three-tier format can identify the relationship among answer, reason, and confidence, whereas the parallel format can reveal whether students’ conceptual understanding is retained when problem context changes. Therefore, the parallel three-tier diagnostic test provides richer diagnostic information than a single multiple-choice item, although its interpretation should remain cautious because it depends on the quality and equivalence of the parallel pairs.

The gap between sound conceptual understanding and answer consistency is an important finding. The average sound conceptual understanding category reached 51.19%, but the average consistency was only 29.48%. This gap suggests that some students may have selected correct answers and reasons in certain items but still relied on contextual clues or memorized procedures. When the same concept was framed differently, many students failed to maintain their answer pattern. In chemistry learning, this type of instability is problematic because conceptual knowledge should be transferable across contexts, representations, and problem situations.

The findings can be explained through the chemistry triplet perspective. Thermochemistry requires students to integrate macroscopic observations, submicroscopic explanations, and symbolic representations (Taber, 2013). For example, in calorimetry, students observe a temperature increase, infer heat transfer between system and surroundings, and calculate enthalpy change using equations. In Hess law, students manipulate symbolic equations while maintaining the conceptual meaning of reaction direction and enthalpy sign. In bond energy, students must imagine bond breaking and bond formation at the particle level while using symbolic energy values. Students who do not connect these representations tend to solve problems mechanically and inconsistently.

The relatively high misconception-related percentages in Hess law and bond energy are consistent with earlier studies showing that thermochemistry difficulties often emerge in concepts that combine abstract energy reasoning and mathematical procedures

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(Roghdah et al., 2021; Yanti et al., 2024). Students frequently memorize formulas such as enthalpy equals energy of bonds broken minus energy of bonds formed, but they do not understand why bond breaking requires energy and bond formation releases energy. This leads to errors in choosing which bonds are broken and formed, reversing the formula, or ignoring stoichiometric coefficients. Nevertheless, not every incorrect response should be interpreted as a stable misconception, because calculation error, misreading, or limited familiarity with item context may also contribute to incorrect answer patterns.

The misconception pattern in exothermic and endothermic reactions also shows that students' everyday experiences may interfere with scientific interpretation. Many students associate heat, hot objects, or initial heating with endothermic processes, even when the overall reaction releases heat. This misconception is similar to the findings of Sihaloho et al. (2021), Irfandi et al. (2022), and Widyaningsih and Aloysius (2024), who reported that students often struggle to interpret heat transfer direction correctly in thermochemistry. Teachers therefore need to emphasize the system-surroundings frame explicitly and repeatedly so that students can distinguish the heat experienced by the surroundings from the energy change of the chemical system.

Pedagogically, the results imply that thermochemistry instruction should move beyond formula practice. Teachers should use multi-representation activities, experiments or simulations, concept maps, and guided comparison of parallel problems. Students should be trained to explain why a reaction is exothermic or endothermic, why a sign changes when a reaction is reversed, and why the number of bonds or moles changes the calculated enthalpy. Parallel problem comparison can help students recognize whether they are applying a concept consistently or merely following a familiar calculation pattern. The parallel diagnostic results can also help teachers identify which concepts require remediation before students move to more advanced chemistry topics.

This study has several limitations. The participants were limited to grade XI students at one senior high school in Gorontalo, so the findings should not be generalized without considering school context, previous learning experience, and teacher strategy. The study was descriptive and did not test a remediation model. In addition, the diagnostic categories were based on written test responses; interviews could provide deeper information about students' reasoning processes. The confidence tier used a binary scale, which may not capture the full range of students' certainty. The equivalence of parallel item pairs also needs further empirical strengthening in future studies, especially because consistency interpretation depends on the assumption that paired items measure the same concept with comparable difficulty.

4. CONCLUSION

Students' thermochemistry conceptual understanding based on answer consistency was categorized as low. The average consistency across 10 parallel indicators was 29.48%, whereas the average inconsistency reached 70.52%. The highest consistency was found in determining reaction type based on enthalpy change, while the lowest consistency was found in analyzing reaction enthalpy using bond energy data. These findings indicate that most students had not developed stable conceptual understanding across equivalent thermochemistry contexts, especially when concepts required the integration of representation, calculation, and conceptual reasoning.

The average sound conceptual understanding category at the individual-item level was 51.19%, while misconception-related and lack of conceptual understanding categories were still found in all indicators. The percentages of M1 (correct answer, incorrect reason, confident), M2 (incorrect answer, correct reason, confident), M3 (incorrect answer, incorrect reason, confident), and lack of conceptual understanding were 11.19%, 16.84%, 10.04%, and 10.85%, respectively. The difference between the 51.19% individual-item conceptual understanding and the 29.48% paired-item consistency shows that correct responses on single items do not necessarily indicate stable conceptual understanding. The dominant difficulties occurred in concepts involving Hess law, calorimetry, average bond energy, and reaction enthalpy from bond energy data.

The parallel three-tier diagnostic test can provide useful information about both students' diagnostic response categories and the stability of their understanding across equivalent item contexts. However, this conclusion should be interpreted cautiously because the study involved a restricted sample, did not include interview data, used a binary confidence scale, and still requires further evidence of parallel item equivalence and person separation. Future research is recommended to combine this diagnostic approach with remedial learning based on multiple representations, inquiry, or problem-based learning, and to include interviews for exploring students' reasoning in greater depth. Instructional development should particularly support students' transfer across macroscopic heat phenomena, submicroscopic energy changes, and symbolic enthalpy calculations.

5. ACKNOWLEDGEMENTS

The authors express sincere appreciation to the participating senior high school in Gorontalo, the chemistry teacher, and the grade XI students for their support and participation during the research. Institutional permission and participant consent were obtained before data collection, and the school and student identities are reported anonymously to protect confidentiality. The authors also thank all parties who provided constructive input during instrument development and manuscript preparation. This research did not receive specific financial support from any funding agency.

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