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Enhancing Students' Conceptual Understanding of Hess's Law Through a Discovery Learning Model Integrated with a Simulator and Worksheets

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Abstract

This study addresses the limited integration of Discovery Learning, a Hess's Law Enthalpy Change Determination Simulator, and student worksheets (LKM). These components have generally been implemented separately or in different combinations in previous studies, and simulation-based learning in Hess's Law remains limited. The study aimed to examine students' conceptual understanding of Hess's Law, both overall and across specific learning objectives, after implementing the Discovery Learning model integrated with a Hess's Law Enthalpy Change Determination Simulator and student worksheets. The research employed a pre-experimental one-group pretest–posttest design involving 29 senior high school students. Data from the conceptual understanding test were analyzed using descriptive and inferential statistics. The paired-sample t-test revealed a statistically significant improvement from 35.06 to 63.22 ($t = -8.11$, $p < 0.001$). At the level of specific learning objectives, the Wilcoxon signed-rank test showed that students achieved greater gains in inferring Hess's Law from comparisons of reaction pathways than in determining enthalpy change based on Hess's Law. These findings indicate that the instructional approach was associated with improved conceptual understanding of Hess's Law. This study suggests that integrating Discovery Learning with a Hess's Law Enthalpy Change Determination Simulator and structured worksheets may support students' conceptual understanding of Hess's Law and serve as a practical instructional strategy in chemistry education.

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1. INTRODUCTION

Chemical concepts are generally abstract, often leading to learning difficulties and misconceptions among students (Mekwong & Chamrat, 2021). One such concept characterized by its abstract and complex nature is Hess's Law (Defista & Aznam, 2024). When studying Hess's Law, students must understand how to manipulate thermochemical equations through algebraic operations, changes in the sign and magnitude of enthalpy (ΔH) resulting from the reversal or multiplication of reactions. Additionally, students must understand that enthalpy change is independent of the reaction pathway and depends solely on the initial and final state of the system (Atkins et al., 2023). These conceptual demands require students to integrate multiple representations, including symbolic chemical equations, mathematical enthalpy change (ΔH) calculations, and visual energy diagrams depicting reaction pathways (Syahri et al., 2021). Consequently, students continue to experience difficulty in determining enthalpy change using Hess's Law (Yanti et al., 2024).

Students still struggle to understand thermochemistry concepts related to Hess's Law, particularly in balancing chemical equations, manipulating thermochemical equations, and performing mathematical calculations to determine the enthalpy change (ΔH), indicating a low level of conceptual understanding of Hess's Law (Rahmi & Azra, 2023; Yanti

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et al., 2024). They also have difficulty interpreting energy-level diagrams of enthalpy changes (Rosyida et al., 2024). Furthermore, students hold the misconception that enthalpy change depends on the number of reaction stages; they assume that reactions with more stages result in greater enthalpy change (Hidayat et al., 2024). These learning difficulties highlight the need for instructional approaches that support students' conceptual understanding of Hess's Law.

Interactive simulations can facilitate the learning of abstract chemistry concepts (Hu-Au, 2024). Educational simulations are designed to represent the phenomena under study, providing learners with opportunities to investigate these phenomena and engage in reasoning based on information generated by the simulation (McLaughlin & Farris, 2025). Through digital representations, simulations foster students' understanding of concepts and the relationships among them, particularly those associated with phenomena that cannot be directly observed, thereby supporting conceptual understanding (Ajayan et al., 2025; Rahmawati et al., 2022). Furthermore, simulations enable students to manipulate the systems or reactions being investigated (Jere & Mpeta, 2024) while providing immediate feedback that supports reflection and self-correction throughout the learning process (Elendu et al., 2024; Mirchi et al., 2020). Collectively, these characteristics indicate that simulations serve not only as a means of presenting knowledge but also as knowledge-building tools (McLaughlin & Farris, 2025). Educational simulators embody these characteristics by representing objects, processes, or systems and responding to users' actions (Lioce et al., 2025). However, the educational contribution of simulators depends not only on the technology itself but also on how they are integrated into an appropriate instructional model or learning (Palacios et al., 2024; Yindeemak et al., 2026; Chernikova et al., 2020). Therefore, an appropriate instructional model is essential to maximize the educational potential of simulations.

To maximize these benefits, the simulator was integrated within the Discovery Learning model, which provides a structured framework for guiding students' exploration, information processing, and knowledge construction through discovery activities (Ozdem-Yilmaz & Bilican, 2025). Discovery Learning was adopted in this study because it emphasizes student-centered learning, in which learners actively construct knowledge through inquiry-driven activities rather than passively receiving information (Abdillah et al., 2025). Grounded in constructivist learning theory, Discovery Learning facilitates students' discovery of concepts and principles through structured learning stages involving exploration and information processing, and conceptual interpretation (Juandi et al., 2025). In the context of Hess's Law learning, these characteristics enable students to explore thermochemical relationships, manipulate thermochemical equations, and construct conceptual understanding through guided investigation. However, effective implementation of Discovery Learning requires appropriate instructional guidance, such as scaffolding and structured learning support, to help students construct scientifically accurate conceptual understanding (Alfieri et al., 2011). To provide the structured learning support required for Discovery Learning, this study incorporated student worksheets.

Student worksheets can serve as complementary instructional support in Discovery Learning by guiding students' exploration, data analysis, and reasoning processes. When integrated with digital tools, worksheets provide guidance that helps learners interpret information and develop conceptual understanding (Abdillah et al., 2025). As instructional tools, worksheets facilitate students' meaning-making by supporting conceptual reasoning and the interpretation of information throughout active learning processes (Koretsky et al., 2018). Furthermore, well-designed worksheets promote active engagement and conceptual understanding through structured learning activities rather than merely presenting content summaries and practice exercises (Anggraini & Susilowati, 2022). They can also be designed to incorporate multiple chemical representations that support students' understanding of abstract chemistry concepts (Syauqiah et al., 2024).

Accordingly, this study integrates a Hess's Law enthalpy change determination simulator, Discovery Learning, and student worksheets into a unified instructional framework. Within this framework, the simulator enables students to manipulate thermochemical equations and provides immediate feedback; Discovery Learning guides students' exploration, information processing, and conceptual construction through structured discovery activities; and the student worksheets provide multiple chemical representations and structured instructional scaffolding to support students' exploration, reasoning, and conceptual understanding throughout the learning process.

Previous research has generally examined simulations, Discovery Learning, and student worksheets (LKM) separately or in different combinations. Kodani et al. (2019) developed a stepwise inquiry-based laboratory program that supported students' understanding of Hess's Law through experimental investigations and thermochemical reasoning. Similarly, Jaraie & Lajium (2020) found that argument-based inquiry laboratory activities enhanced students' conceptual understanding of Hess's Law energy cycle through scientific argumentation. However, these studies were conducted in laboratory settings and did not involve interactive digital simulations.

In thermochemistry learning, Biya et al. (2023) reported that Discovery Learning significantly improved students' conceptual understanding; however, their study did not incorporate interactive simulation media and did not specifically address Hess's Law. Furthermore, Simanjuntak et al. (2026) demonstrated that Discovery Learning integrated with Javalab simulation significantly improved students' conceptual understanding and learning interest in chemical bonding, although the study focused on a different chemistry topic. Patricia et al. (2025) also demonstrated that a chemistry simulator integrated with the Predict–Observe–Explain (POE) model and supported by student worksheets facilitated conceptual understanding by combining interactive visualization with structured instructional scaffolding. However, their study focused on coagulation concepts rather than Hess's Law.

Previous studies have generally examined simulations, Discovery Learning, and student worksheets (LKM) separately or in partial combinations. However, the integration of an interactive Hess's Law simulator with Discovery Learning and LKM remains underexplored. Therefore, the present study extends previous research by implementing an integrated instructional approach that combines Discovery Learning, a Hess's Law Enthalpy Change Determination Simulator, and LKM as instructional scaffolding to facilitate students' conceptual understanding of Hess's Law.

Three aspects distinguish this study from previous research. First, this study integrates the Discovery Learning model, a Hess's Law enthalpy change determination simulator, and student worksheets (LKM) into a single instructional framework. Second, it employs a Hess's Law–specific interactive simulator that enables students to construct and manipulate chemical equations and calculate enthalpy changes based on Hess's Law. Third, it provides a more comprehensive evaluation by analyzing learning outcomes based on each learning objective rather than solely on overall achievement scores.

In light of the research problems and gaps identified in previous studies, this study aims to examine students' conceptual understanding of Hess's Law, both overall and across specific learning objectives, following the implementation of the Discovery Learning model, Hess's Law Enthalpy Change Determination Simulator, and student worksheets (LKM).

2. METHOD

A one-group pretest-posttest pre-experimental design was employed in this study. The research design is presented in Table 1.

Table 1. Research design

Pretest	Treatment	Posttest
O_1	X	O_2

In this notation, O_1 represents the pretest, X refers to the instructional intervention consisting of Discovery Learning integrated with Hess's Law Enthalpy Change Determination Simulator and student worksheets (LKM), and O_2 represents the posttest.

This study was conducted at a public senior high school in Bandung, Indonesia, during the 2025/2026 academic year, involving 29 eleventh-grade students aged 16-17 years. Participants were selected using purposive sampling based on the criterion that the students had completed the prerequisite thermochemistry topic and had never used Hess's Law Enthalpy Change Determination Simulator in their learning. The learning activities were facilitated by the researcher as the instructor. During the learning activities, students used smartphones connected to the school's internet to access and operate the interactive simulator.

The research was conducted through a systematic series of stages. First, Hess's Law Enthalpy Change Determination Simulator was evaluated to determine its alignment with the instructional phases of the Discovery Learning model. Based on this analysis, a lesson module and student worksheets (LKM) were developed and integrated with the simulator. Before implementation, all instructional materials and research instruments underwent expert validation.

This study began with a pretest to assess students' baseline conceptual understanding, followed by an instructional intervention using the simulator-integrated Discovery Learning model and student worksheet (LKM). The instructional activities were designed according to the six stages of the Discovery Learning model: stimulation, problem statement, data collection, data processing, verification, and generalization.

During the stimulation stage, the student worksheet (LKM) was used to present the propane combustion phenomenon together with an enthalpy level diagram illustrating both the direct and indirect reaction pathways. Guiding questions were then used to activate students' prior knowledge and encourage them to identify the learning problem. During the problem statement stage, the student worksheet (LKM) guided students in formulating problem statements concerning the relationship between reaction pathways and enthalpy changes and recording them in the worksheet.

During the data collection stage, the Hess's Law Enthalpy Change Determination Simulator was used to enable students to examine thermochemical reaction data and the corresponding enthalpy values (ΔH), construct the target reaction using the drag-and-drop feature, balance chemical equations, manipulate reactions by reversing equations or multiplying coefficients, observe the resulting changes in enthalpy values (ΔH), combine individual reactions into an overall reaction, and determine the enthalpy change of the overall reaction. At the same stage, the student worksheet (LKM) was used to record the results obtained from the simulator and complete Hess's Law representations in the form of a Hess cycle.

During the data processing stage, the simulator was used to present conceptual questions related to the manipulation of thermochemical equations and the determination of enthalpy changes (ΔH), enabling students to evaluate their understanding of the concepts explored in the simulation. At the same stage, the student worksheet (LKM) was used to guide students in comparing the enthalpy changes of direct and indirect reaction pathways, analyzing the relationship between reaction pathways and enthalpy changes, and identifying the principle of Hess's Law through a series of guiding questions.

During the verification stage, the simulator provided immediate feedback on students' responses to simulator activities, including equation manipulation, enthalpy calculations, conceptual questions, and conclusion statements, enabling them to verify the correctness of their responses. Teacher verification subsequently focused on students' responses to the guiding questions in the student worksheet (LKM). When misconceptions or incorrect responses were identified, the teacher provided clarification, after which students revised and recorded the corrected responses in the student worksheet (LKM).

Finally, during the generalization stage, students integrated the results obtained from the simulator with their analyses recorded in the student worksheet (LKM) to formulate the principle of Hess's Law: the enthalpy change of a reaction is independent of the reaction pathway.

During the intervention, classroom observations were systematically conducted to monitor implementation fidelity. After the intervention, a posttest was administered to assess changes in students' conceptual understanding. Finally, the collected data were analyzed to examine implementation fidelity and students' conceptual understanding.

Data were collected using 12-item multiple-choice tests assessing students' conceptual understanding, developed based on learning objectives, indicators, and cognitive levels. This instrument assessed students' conceptual understanding of determining enthalpy change based on Hess's Law through thermochemical equations and the Hess cycle, as well as the inference of Hess's Law from comparisons of reaction pathways represented by thermochemical equations and energy-level diagrams. The test consisted of two learning objectives, each with two indicators, and three items assigned to each indicator. The items were categorized at cognitive levels C3 and C4 based on the revised Bloom's taxonomy (Anderson & Krathwohl, 2001).

Prior to implementation, the conceptual understanding test was validated through expert judgment by two chemistry education lecturers and one chemistry teacher. The validation process was conducted to establish the content validity of the test items by evaluating their relevance, clarity, and alignment with the

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learning objectives and indicators (Koller et al., 2017). This strategy was employed to ensure that the instrument items adequately represented the intended constructs, thereby strengthening the instrument's content validity (Lim, 2024).

Based on the experts' evaluations and feedback, the test instrument was considered suitable for use after revisions were made in accordance with their suggestions. The revised instrument was subsequently administered to assess students' conceptual understanding of Hess's Law.

The distribution of students' conceptual understanding of Hess's Law is presented in Table 2.

Table 2. Distribution of conceptual understanding of Hess Law.

Learning Objective	Item indicator	Item Number	Cognitive Level
Students can accurately determine the enthalpy change (ΔH) of a reaction through the manipulation of thermochemical equations and the application of Hess's Law cycles	Given several thermochemical equations, students can determine the enthalpy change (ΔH) of a target reaction through the manipulation and combination of thermochemical equations correctly	1-3	C3
	Given a Hess's Law cycle diagram, students can correctly calculate the enthalpy change (ΔH) of a reaction	4-6	C3
Students can accurately draw conclusions regarding the principle of Hess's Law by comparing different reaction pathways and their enthalpy changes	Given several thermochemical equations with different reaction pathways, students are able to correctly derive the principle of Hess's Law.	7-9	C4
	Given energy level diagrams of different reaction pathways, students can correctly derive the principle of Hess's Law.	10-12	C4

Data on students' conceptual understanding were analyzed using descriptive and inferential statistics. Descriptive statistics included the maximum score, mean, and standard deviation of pretest and posttest results. Data normality was examined using the Shapiro-Wilk test. Based on the normality results, a paired-sample *t*-test was conducted for normally distributed data, while the Wilcoxon Signed-Rank Test was applied for non-normally distributed data to examine differences in students' conceptual understanding before and after the instructional intervention (Field, 2018; Pallant, 2020). In addition, gain scores, calculated as the difference between the mean posttest and pretest scores, were used to compare the magnitude of improvement across the two learning objectives. All statistical analyses were performed using SPSS Statistics 26 (Fauzi, 2023) with a significance level of 0.05.

3. RESULT AND DISCUSSION

3.1. Result

Students' Conceptual Understanding

Students' conceptual understanding was evaluated by comparing pretest and posttest scores following the implementation of the Discovery Learning model integrated with Hess's Law Enthalpy Change Determination Simulator and student worksheets (LKM).

Descriptive statistics were used to describe students' conceptual understanding before and after the instructional intervention (Table 3).

Table 3. Descriptive statistics of students' conceptual understanding

	Pretest	Posttest
N	29	29
Minimum	8.33	16.67
Maximum	75.00	100.00
Mean	35.06	63.22
Standard deviation	19.72	18.44

The mean score increased from 35.06 to 63.22 (Table 3), indicating an improvement in conceptual understanding after the instructional intervention. In addition, the decrease in standard deviation suggests a reduction in score variability among students. To examine the assumption of normality, a Shapiro-Wilk test was conducted. The results are presented in Table 4.

Table 4. Results of the Shapiro-Wilk test

	Shapiro-Wilk		
	Statistic	df	Sig.
Pretest	0.931	29	0.057
Posttest	0.958	29	0.288

The Shapiro-Wilk test (Table 4) showed that both the pretest and posttest data were normally distributed ($p > 0.05$). Therefore, the paired-samples *t*-test was used to analyze the differences between pretest and posttest scores. The results are presented in Table 5.

Table 5. Results of the Paired-Sample *t*-test

	Paired Differences		t	df	Sig. (2-tailed)
	Mean	SD			
Pretest-Posttest	-28.16	18.69	-8.11	28	<0.001

The result of the paired-samples *t*-test (Table 5) indicated a statistically significant difference between the pretest and posttest scores ($t = -8.114$, $p < 0.001$), suggesting that students' conceptual understanding improved after the instructional intervention.

Students' Conceptual Understanding Based on Learning Objective

Students' conceptual understanding of Hess's Law was also analyzed based on each learning objective.

Learning Objective 1: Determine the enthalpy change (∆H) of reaction through the manipulation of thermochemical equations and application of Hess's Law cycles

Descriptive statistics of students' conceptual understanding for Learning Objective 1 are presented in Table 6.

Table 6. Descriptive statistics of students' conceptual understanding for learning objective 1

	Pretest	Posttest
N	29	29
Minimum	0.00	0.00
Maximum	83.33	100.00
Mean	29.89	44.25
Standard deviation	21.99	24.91

The mean score increased from 29.89 to 44.25 (Table 6), indicating an improvement in conceptual understanding after the instructional intervention. In addition, changes in score variability among students were observed in the posttest. To examine the assumption of normality, a Shapiro-Wilk test was conducted. The results are presented in Table 7.

Table 7. Results of the Shapiro-Wilk test

	Shapiro-Wilk		
	Statistic	df	Sig.
Pretest	0.903	29	0.012
Posttest	0.947	29	0.155

The Shapiro-Wilk test indicated that the pretest data were not normally distributed ($p = 0.012$), whereas the posttest data were normally distributed ($p = 0.155$). Since one dataset violated the assumption of normality, the subsequent analysis was performed using the Wilcoxon signed-rank test. for Learning Objective 1 are presented in Table 8.

Table 8. Results of the Wilcoxon signed-rank test

	Z	Asymp.Sig. (2-tailed)
Pretest-Posttest	-2.672	0.008

As shown in Table 8, the Wilcoxon signed-rank test indicated a statistically significant difference between the pretest and posttest scores for Learning Objective 1 ($Z = -2.672$, $p = 0.008$). This finding indicates that students' conceptual understanding of Learning Objective 1 showed a significant improvement following the instructional intervention.

Learning Objective 2: Draw conclusions regarding the principle of Hess's Law by comparing different reaction pathways and their enthalpy change (∆H)

Descriptive statistics of students' conceptual understanding for Learning Objective 2 are presented in Table 9.

Table 9. Descriptive statistics of students' conceptual understanding for learning objective 2

	Pretest	Posttest
N	29	29
Minimum	0.00	16.67
Maximum	83.33	100.00
Mean	40.23	82.18
Standard deviation	28.00	20.38

As shown in Table 9, the mean score increased from 40.23 to 82.18, indicating an improvement in students' conceptual understanding after the instructional intervention. In addition, the decrease in standard deviation suggests a reduction in score variability among students. To examine the assumption of normality, a Shapiro-Wilk test was conducted. The results are presented in Table 10.

Table 10. Results of the Shapiro-Wilk test

	Shapiro-Wilk		
	Statistic	df	Sig.
Pretest	0.894	29	0.007
Posttest	0.762	29	< 0.001

As presented in Table 10, the Shapiro-Wilk test indicated that both the pretest and posttest data were not normally distributed ($p < 0.05$). Therefore, the Wilcoxon signed-rank test was used to analyze the differences in Learning Objective 2, which are presented in Table 11.

Table 11. Results of the Wilcoxon signed-rank test

	Z	Asymp.Sig. (2-tailed)
Pretest-Posttest	-4.559	< 0.001

As shown in Table 11, the Wilcoxon signed-rank test indicated a statistically significant difference between the pretest and posttest scores for Learning Objective 2 ($Z = -4.559$, $p < 0.001$). This finding indicates that students' conceptual understanding of Learning Objective 2 improved significantly following the instructional intervention.

To further compare the magnitude of improvement between the two learning objectives, gain scores were calculated for each learning objective, as presented in Table 12.

Table 12. Comparison of mean scores and gain scores for each learning objective

Learning Objective	Mean Pretest	Mean Posttest	Gain Score
Learning objective 1. Determine the enthalpy change (ΔH) of reaction through the manipulation of thermochemical equations and application of Hess's Law cycles	29.89	44.25	14.36
Learning objective 2. Draw conclusions regarding the principle of Hess's Law by comparing different reaction pathways and their enthalpy change (ΔH)	40.23	82.18	41.95

As shown in Table 12, learning objective 2 showed a larger gain than learning objective 1. These results suggest that the magnitude of improvement differed between the two learning objectives.

The results showed significant improvements in students' conceptual understanding. Statistically significant differences were observed not only in overall conceptual understanding but also across both learning objectives. These findings suggest that the magnitude of improvement varied across the learning objectives.

3.2. Discussion

This study examined students' conceptual understanding of Hess's Law following the implementation of a Discovery Learning model integrated with a Hess's Law enthalpy change determination simulator and student worksheets (LKM). The paired-samples t-test indicated a statistically significant difference between students' pretest and posttest scores (t= -8.114, p < 0.001), suggesting an improvement in their overall conceptual understanding of Hess's Law following the instructional intervention.

This improvement may be associated with the integrated instructional design combining Discovery Learning, the Hess's Law enthalpy change determination simulator, and student worksheets (LKM). Rather than functioning independently, these instructional components complemented one another throughout the learning process. The integration of these components provided opportunities for students to explore the concept of Hess's Law, engage with thermochemical representations, and construct their understanding through guided discovery activities. Therefore, the observed improvement may be interpreted as reflecting the role of the integrated instructional approach rather than the effect of any single instructional component.

The characteristics of Discovery Learning were reflected in the learning activities through the integration of Hess's Law Enthalpy Change Determination Simulator and student worksheets (LKM). The Discovery Learning framework provided a structured process that guided students to explore Hess's Law concepts, process information, verify their findings, and formulate conclusions based on their investigation. This implementation reflects the characteristics of Discovery Learning described by Ozdem-Yilmaz & Bilican (2025), who emphasized that Discovery Learning facilitates students' active involvement in exploration, information processing, and knowledge construction through structured discovery activities. Within this framework, students were encouraged to construct their understanding by identifying relationships among reaction pathways, thermochemical equations, and enthalpy changes rather than merely applying predetermined calculation procedures. This learning process is consistent with constructivist principles, in which learners actively construct knowledge through exploration and discovery (Bruner, 2006)

Within this framework, Hess's Law enthalpy change determination simulator facilitated students' exploration of Hess's Law concepts by providing opportunities to manipulate thermochemical equations, including reversing reaction directions and adjusting

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reaction coefficients, while observing the resulting changes in enthalpy values (∆H). Students were also able to combine multiple thermochemical equations to construct the target reaction and evaluate the consistency between the calculated enthalpy change and Hess's Law. These activities provided opportunities for students to engage with the relationships among thermochemical equations, reaction pathways, and enthalpy changes rather than merely applying predetermined calculation procedures. This learning process is supported by previous literature indicating that simulations can facilitate active exploration by providing learners with opportunities to investigate phenomena and engage in reasoning based on information generated by the simulation (McLaughlin & Farris, 2025). Furthermore, previous studies have indicated that simulations can support chemistry learning when they are integrated within appropriate instructional designs that promote active exploration and conceptual visualization (Palacios et al., 2024; Chernikova et al., 2020).

The student worksheets (LKM) complemented the learning process by providing structured guidance throughout Discovery Learning. In this study, the student worksheets (LKM) functioned as instructional scaffolding that supported students in identifying learning problems, organizing information, recording simulation results, analyzing the relationship between reaction pathways and enthalpy changes, and constructing conceptual conclusions regarding Hess's Law. This role is consistent with previous research indicating that student worksheets can support students' exploration, reasoning, and interpretation of information during active learning processes (Koretsky et al., 2018; Anggraini & Susilowati, 2022). Furthermore, the student worksheet (LKM) provided multiple representations, including a contextual phenomenon, Hess cycle diagrams, and energy-level diagrams, which helped students relate different representations to relationships among reaction pathways and enthalpy changes. The use of multiple representations in the student worksheet (LKM) is consistent with previous studies indicating that incorporating multiple representations in chemistry learning can support students' understanding of abstract chemical concepts (Syauqiah et al., 2024).

Overall, the integration of Discovery Learning, Hess's Law enthalpy change determination simulator, and the worksheets (LKM) provided a complementary instructional framework that supported students' conceptual understanding of Hess's Law. The Discovery Learning structured the learning process, the simulator facilitated interactive exploration, and the LKM provided instructional scaffolding and multiple representations to support students' conceptual interpretation. This integrated approach is consistent with previous findings indicating that the educational contribution of simulations depends not only on technological features but also on their integration with appropriate instructional models and learning support (Palacios et al., 2024; Yindeemak et al., 2026; Chernikova et al., 2020).

Students' Conceptual Understanding Based on Learning Objectives

In addition to the overall improvement in students' conceptual understanding, the Wilcoxon signed-rank test revealed statistically significant differences between the pretest and posttest scores for both learning objectives. The higher posttest scores indicate an improvement in students' conceptual understanding in determining enthalpy changes through the manipulation of thermochemical equations and application of the Hess cycle (Learning Objective 1), as well as in drawing conclusions about the principle of Hess's law by comparing different reaction pathways (Learning Objective 2). These findings suggest that the instructional intervention was associated with improvements in conceptual understanding across both learning objectives. However, the magnitude of the gains differed, with greater improvement observed in drawing conclusions about the principle of Hess's Law by comparing different reaction pathways than in determining enthalpy changes through the manipulation of thermochemical equations and the application of the Hess cycle.

The significant improvement in Learning Objective 1 may be attributed to the integration of Discovery Learning, the Hess's Law Enthalpy Change Determination Simulator, and the student worksheet (LKM). During the data collection stage of Discovery Learning, students actively explored strategies for determining enthalpy changes by investigating thermochemical reaction data and manipulating thermochemical equations to construct the target reaction. The Hess's Law Enthalpy Change Determination Simulator enabled students to reverse equations, multiply coefficients, combine individual

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reactions into an overall reaction, and observe the corresponding changes in enthalpy values (ΔH). During the data processing stage, students analyzed the results of these manipulations to determine the enthalpy change of the target reaction. The simulator supported this process by providing conceptual questions that encouraged students to evaluate their understanding, while the student worksheets guided students through structured questions to record, analyze, and interpret the simulation results, complete Hess's Law representations through the Hess cycle, and relate the procedures used to the application of Hess's Law. Together, these complementary learning experiences may have supported students' procedural understanding of determining enthalpy changes through the application of Hess's Law.

Similarly, the significant improvement in Learning Objective 2 may be attributed to the integration of Discovery Learning, the Hess's Law Enthalpy Change Determination Simulator, and the student worksheets (LKM). During the stimulation and problem statement stages of Discovery Learning, students activated their prior knowledge and formulated the learning problem concerning the relationship between reaction pathways and enthalpy changes. The student worksheets facilitated this process by presenting the propane combustion phenomenon, an enthalpy level diagram, and structured guiding questions. During the data collection stage, students explored different reaction pathways and gathered evidence for subsequent analysis. The simulator enabled them to compare direct and indirect reaction pathways and observe the corresponding enthalpy changes. During the data processing stage, students analyzed the evidence they had collected to identify the relationship between reaction pathways and enthalpy changes. The student worksheets supported this process through structured questions that guided students in comparing the enthalpy changes associated with different reaction pathways and identifying the principle of Hess's Law based on the simulation results. During the verification stage, students evaluated the accuracy of their interpretations using the immediate feedback provided by the simulator together with teacher verification of their worksheets responses. Finally, during the generalization stage, students synthesized the evidence obtained throughout the learning process to formulate the principle that the enthalpy change of a reaction is independent of the reaction pathway. Together, these complementary learning experiences may have supported students' conceptual understanding of the path independence principle underlying Hess's Law.

The gains observed in determining enthalpy changes through the manipulation of thermochemical equations and the application of the Hess cycle suggest that students improved their understanding following the instructional intervention. Nevertheless, the magnitude of the improvement for this learning objective was smaller than that observed in drawing conclusions about the principle of Hess's Law by comparing direct and indirect reaction pathways. This difference may be attributed to the cognitive demands of determining enthalpy change, which required students to integrate conceptual understanding of Hess's Law with procedural skills in manipulating thermochemical equations. This interpretation is consistent with Condong et al. (2026), who stated that students must first understand the fundamental concepts of thermochemistry before progressing to more complex calculations, including calculations involving Hess's Law.

Greater improvement was observed in drawing conclusions about Hess's Law by comparing direct and indirect reaction pathways. Within the Discovery Learning framework, students were guided to explore, verify, and generalize the relationships among reaction pathways and enthalpy changes. During this process, the Hess's Law Enthalpy Change Determination Simulator enabled students to manipulate thermochemical equations and observe the resulting changes in enthalpy (ΔH), while the student worksheets (LKM) provided Hess cycles and energy-level diagrams that supported comparisons between direct and indirect reaction pathways and their associated enthalpy changes. Through these complementary learning activities, students had opportunities to relate enthalpy changes to the initial and final states of the system and develop an understanding of the path independence principle underlying Hess's Law. The greater improvement observed in this learning objective may be related to the conceptual nature of this objective, which emphasized understanding the relationship between reaction pathways and enthalpy changes.

Overall, this study indicated that the implementation of Discovery Learning integrated with a

Hess's Law enthalpy change simulator and student worksheets (LKM) was associated with an improvement in students' conceptual understanding of Hess's Law. These findings extend previous studies that have examined virtual simulations, Discovery Learning, or student worksheets separately by investigating the integration of these three components within a single instructional sequence. Furthermore, the analysis based on the learning objectives provides a more detailed understanding of students' conceptual development across different aspects of Hess's Law. Such information may assist teachers in identifying learning objectives that require greater instructional emphasis during the teaching and learning process.

This study has several limitations. First, a one-group pretest–posttest design was employed without a control group, which limits the ability to draw causal inferences regarding the observed changes. Second, the sample was limited to a single class from one school, thereby restricting the extent to which the findings can be generalized to other educational contexts.

This study contributes to chemistry education research by demonstrating that the integration of Discovery Learning with a virtual simulator and student worksheets was associated with improved students' conceptual understanding of Hess's Law. These findings provide practical implications for teachers in designing interactive and visually based learning environments to support the understanding of abstract chemical concepts. In addition, the results of this study may serve as a reference for developing instructional strategies that combine simulation with structured discovery to support students' learning outcomes.

4. CONCLUSION

This study examined students' conceptual understanding of Hess's Law following the implementation of a Discovery Learning model integrated with a Hess's Law Enthalpy Change Determination Simulator and student worksheets (LKM). The findings indicate that this instructional approach was associated with improved students' conceptual understanding of Hess's Law. The paired-samples t-test revealed a statistically significant improvement in overall conceptual understanding of Hess's Law, while the Wilcoxon signed-rank test confirmed significant improvements across both learning objectives, with greater gains observed in drawing conclusions about Hess's Law through comparison of reaction pathways than in determining enthalpy changes through thermochemical equation manipulation and the application of the Hess cycle. These findings suggest that integrating Discovery Learning with an interactive simulator and student worksheets (LKM) may serve as an instructional approach for supporting students' conceptual understanding of Hess's Law.

Future studies are encouraged to adopt quasi-experimental designs with appropriate control groups and larger, more diverse samples.

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