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The Effectiveness of the Discovery Learning Model Assisted by Javalab and Hands-on Activities to Improve Students' Conceptual Understanding

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Abstract

Conceptual understanding is essential to science learning, yet Indonesian students still struggle, as evidenced by their low PISA 2022 science literacy score (383). Conventional teacher-centred instruction and limited laboratory facilities further limit opportunities to meaningfully explore and construct scientific concepts. This study aims to analyse the effectiveness of a discovery learning model integrated with JavaLab and hands-on activities in improving students' conceptual understanding of work and energy. This Research used a pre-experimental one-group pretest-posttest involving 23 eighth-grade students at SMP Muhammadiyah 3 in Depok. Data were collected using a validated concept understanding test to assess reliability and analysed using descriptive statistics, normality tests, paired-samples t-tests, N-gain, and effect sizes. The findings showed that the mean score increased from 52.2 to 85.6, indicating a significant difference (Sig. = 0.000), with an N-gain of 0.69 (moderate). These results suggest that integrating virtual laboratories and hands-on activities within discovery learning can facilitate students' conceptual understanding through exploration, verification, and concept generalisation. These findings suggest that teachers can adopt this approach to teach abstract concepts in schools with limited laboratory facilities. Future Research should use a quasi-experimental design with a control group and explore its application across broader topics and populations.

1. INTRODUCTION

Science learning has shifted its orientation from simply delivering content to understanding science as a human activity that emphasizes active inquiry, reasoning, and knowledge construction (Hodson, 1985; Lederman et al., 2002). Effective science learning should provide opportunities for students to actively participate in the process of scientific inquiry, allowing them to develop significant conceptual understanding through engaging and thoughtful learning experiences (Driver et al., 1994; Welch et al., 1981).

Conceptual understanding is a fundamental component in science learning because students' ability to explain phenomena, interpret data, and solve scientific problems depends heavily on the quality of their conceptual understanding (OECD, 2018). The ability to accurately understand concepts enables students to solve problems more effectively, as they can apply their knowledge appropriately in different contexts (Mariana & Kinasih, 2021). From a constructivist perspective, conceptual understanding is formed through an active cognitive process when students relate new experiences to their prior knowledge, so learning needs to provide space for exploration, discussion, and reflection (Chiappetta & Koballa, 2010; Driver et al., 1994). However, various research results indicate that students' conceptual understanding in Indonesia remains below expectations (Lestari et al., 2021). The results of the PISA 2022 demonstrated that Indonesia's scientific literacy score was 383, far below the OECD average of 485, placing Indonesia at the bottom of the science domain (OECD, 2023).

In line with these findings, studies at the secondary school level indicate that misconceptions remain prevalent across various science topics (Suban et al., 2024; Wiyono et al., 2016). Students' ability to analyse science concepts remains weak (Febriyana et al., 2021). Students encounter obstacles in remembering and understanding science concepts presented by teachers during learning (Safitri et al., 2021). These findings indicate that conceptual understanding issues are not only local but also a recurring, widespread difficulty in science education in Indonesia.

This circumstance is similarly evident in the preliminary outcomes—observations of learning at SMP Muhammadiyah 3 Depok. The teacher still dominates the science learning process as the centre of class activity, while student involvement in conceptual discussions is relatively limited. During the learning process, students have not consistently demonstrated the ability to explain concepts accurately when faced with conceptual questions. Furthermore, limited laboratory facilities at the school hinder the strengthening of conceptual understanding. As a result, students typically receive more Material from the teacher and rarely explore or prove concepts through practical activities. This condition contributes to low student participation in learning, underdevelopment of their ability to understand concepts comprehensively, and also reduced opportunities for collaboration in groups (Ali et al., 2023).

To address these issues, learning strategies are needed that facilitate active student involvement in the discovery of concepts. The discovery learning model is a useful method because it positions students as the primary agents in constructing their understanding through exploration and discovery. (Bruner, 1961). Numerous studies have shown that discovery learning can enhance student achievement and conceptual understanding (Dafira & Widodo, 2021; Jariyah & Efendi, 2024; Muthmainnah et al., 2023). Despite its benefits, the application of discovery learning in educational institutions continues to encounter challenges, primarily because it relies on conventional printed modules and practical activities that are heavily influenced by the availability of laboratory facilities (Hariyani, 2019; Mahrus, 2023). This condition makes the concept discovery process suboptimal, especially in schools with limited laboratory facilities.

To support the concept discovery process in discovery learning, learning media that allow for direct manipulation of variables and observation of phenomena are needed. Various virtual laboratory platforms have been utilized in prior science learning research, including PhET Interactive Simulations, Labster, Algodoo, and Crocodile Physics, each of which has demonstrated benefits in supporting student inquiry and conceptual understanding (Alnaser & Forawi, 2024; Zhang et al., 2024). However, most of these tools are designed as general purpose simulations. They are not specifically structured to align with the syntactic stages of a particular learning model, such as discovery learning. JavaLab, an interactive simulation-based virtual laboratory accessible via a web browser without additional software installation, offers a more contextual and flexible alternative. Virtual laboratories can facilitate students' understanding of abstract concepts, provide safe experimentation opportunities, and are a practical solution when physical laboratory facilities are limited. The advantages of JavaLab include ease of access, the absence of additional devices, and the provision of interactive visualisations that explain abstract science concepts such as work and energy (Tambunan & Sinaga, 2025). Despite the growing use of virtual labs in science education, studies that specifically integrate JavaLab within the discovery-learning framework to improve conceptual understanding remain scarce. This constitutes the research gap that the present study aims to address. To further strengthen students' knowledge and understanding, concrete hands-on activities are also needed.

Recent Research increasingly supports a hybrid approach that combines virtual laboratories and hands-on activities. The use of virtual laboratories is more optimal when combined with hands-on activities. The use of hands-on activities is also an important solution to common misconceptions (Docherty-Skippen et al., 2020). Therefore, integrating virtual and hands-on activities has a significant impact on conceptual retention compared to a single approach (Elnadeef & Abdala, 2025). Students who participate in hybrid learning demonstrate greater engagement and achievement than those who conduct physical practicums (Bortnik et al., 2017). This hybrid approach has been shown to provide a richer learning experience, as students can understand concepts through digital representations and empirical evidence (Kashaka, 2024). Students’ learning experiences are also more effective, contributing to improved learning outcomes (Ouahi et al., 2024). This indicates that the integrated method is highly relevant to science learning, especially when it emphasises discovery and exploration, as in the discovery learning model.

Although the use of virtual laboratories and hands-on activities has been widely studied in science learning, most studies still examine them separately or position them as alternatives to practical work, without clear integration into the learning model’s syntax. In addition, virtual laboratories are often not specifically designed to support concept discovery, the core of discovery learning, so their impact on students’ conceptual understanding is not optimal. Therefore, this study focuses on designing and testing the functional and complementary integration of Javalab and hands-on activities within the discovery-learning framework to improve students' conceptual understanding through more meaningful exploration, verification, and generalisation.

2. METHOD

The approach employed in this Research was a pre-experimental design utilising a one-group pretest-posttest method. Pre-experimental design is considered a preliminary form of experimental Research in which there is no control group and no random selection of participants, so external variables may still influence the dependent variable (Sugiyono, 2019). This design is widely applied in educational Research to evaluate the effectiveness of a learning treatment in a single group (Cohen et al., 2018). The research design involved administering questions before treatment (O1) and after treatment (O2), allowing the two to be compared to assess the effect of a particular treatment (X) (Creswell & Creswell, 2018). The research framework is outlined in Table 1, shown below.

Table 1. One Group Pretest-Posttest Design

Pretest	Treatment	Posttest
O_1	X	O_2

The treatment procedure in this study was carried out over two meetings, each lasting 2 x 40 minutes. During the initial meeting, students took a pretest (O_1) to assess their starting conceptual understanding. Next, learning was conducted using a discovery-based model combined with JavaLab. The second treatment was carried out with direct practical activities (hands-on activity) on the Material of energy changes, and a posttest (O_2) was given to measure the growth in conceptual knowledge after the treatment. This Research took place at SMP Muhammadiyah 3 in Depok, Yogyakarta, during the 2025/2026 academic year. The research sample comprised 23 eighth-grade students who were intentionally selected for their readiness to engage in Javalab-based learning and practical activities. Data were gathered through a test comprising 15 multiple-choice questions organized around indicators of conceptual understanding, including interpreting, providing examples, classifying, drawing inferences, and comparing. Before testing the instrument with students, researchers assessed its validity and reliability. The reliability assessment was carried out by two expert lecturers in the science education department, covering the Material and media aspects. In addition, an empirical test was conducted with ninth-grade students at Muhammadiyah 3 Middle School in Depok, Yogyakarta. Details of conceptual understanding indicators and their corresponding question numbers are presented in Table 2 below.

Table 2. Indicators of Concept Comprehension Question

No.	Concept Comprehension Indicator	Question Number	Number of Questions
1.	Interpret	1, 5, 12	3
2.	Provide an example	4, 14	2
3.	Classifying	3, 6, 7	3
4.	Drawing inferences	8, 10, 13	3
5.	Compare	2, 9, 11,15	4

validated by media and material experts. Question validation was analyzed using Aiken's V, while empirical testing was analyzed using the QUEST program. The results show that all items have an Aiken's V value of 1, indicating a high level of validity, with an INF MNSQ ranging from 0.81 to 1.22 and a reliability score of 0.82. An INF MNSQ value between 0.77 and 1.33 indicates that the items are in accordance with the Rasch model, and a reliability value between 0.70 and 0.90 indicates that the instrument is reliable. The conceptual understanding instrument shows high validity and reliability, making it suitable for use (Hajiriah et al., 2024).

Afterwards, students received instructional intervention using the discovery learning model, combined with JavaLab and hands-on practical activities. Additionally, the data were analysed in SPSS 25, using tests of normality and paired t-tests. In addition, an N-gain assessment was conducted to further evaluate the extent of improvement in students' conceptual understanding. The outcomes of the N-gain test were subsequently classified according to the standards specified by Hake (1998), as shown in Table 3.

Table 3. Category N-gain

Standardized Mean	Category
$g>0.7$	Large
$0.3 \leq g< 0.7$	Medium
$G<0.3$	Small

3. RESULTS AND DISCUSSION

RESULT

The research results demonstrate that integrating the JavaLab-assisted discovery learning model with hands-on activities facilitated students' conceptual understanding. An analysis was performed using pretest and posttest data, employing descriptive statistics, normality tests, paired-samples t-tests, and n-gain assessments.

Descriptive Statistical Analysis of Conceptual Understanding

The enhancement in students' grasp of concepts is clear from the comparison of pretest and posttest scores presented in Table 5.

Table 5. Descriptive Statistics of Concept Understanding

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	23	27	81	52,2	12.697
Posttest	23	77	95	85,6	5.604

Table 5 shows that the average pretest score of 52.2 rose to 85.6 on the posttest. This 33.4% increase indicates that the educational intervention effectively enhanced students' conceptual understanding.

Normality Test

The Shapiro-Wilk test was employed to assess the normality of the pretest and posttest data. The findings from the normality assessment are shown in Table 6.

Table 6. Shapiro-Wilk Normality Test Result

	Statistic	df	Sig.	Descriptive
Pretest	0.933	23	0.126	Normal
Posttest	0.931	23	0.113	Normal

According to Table 6, the pretest results showed a p-value of 0.126 (>0.05), suggesting a normal distribution, while the posttest results showed a p-value of 0.113 (>0.05), also indicating a normal distribution. Given the assumption of normality, a paired-samples t-test was conducted for the parametric statistical analysis.

Paired Sample T-Test

A paired-samples t-test was conducted to examine differences in conceptual understanding before and after the treatment. The findings are displayed in Table 7.

Table 7. Paired Sample T-test Result

	Mean	Std. Deviation	df	Sig. (2-tailed)
Pretest-Posttest	-33.696	10.146	23	0.000

Table 7 shows that the Sig. (2-tailed) The value is 0.000, which is lower than the 0.05 significance level. Based on these results, H0 is rejected, while H1 is accepted. This finding indicates a difference between the posttest and pretest after students received discovery learning treatment through JavaLab and hands-on activities.

N-gain Test

Once a substantial difference was established, a test was conducted to assess students' conceptual understanding. The findings are shown in Table 8.

Table 8. N-Gain Result

	N	Maximum	Minimum	N-Gain	Category
Pretest-Posttest	23	57.45	83.36	0.69	Medium

The average N-gain was 0.69, indicating a significant increase in students' conceptual understanding after implementing the Javalab-assisted discovery learning model and hands-on activities. Furthermore, Table 9 provides a detailed overview of student achievement by presenting n-gain results for five indicators of conceptual understanding

Table 9. N-Gain Results of Each Indicator

Indicator	N-gain	Category
Interpret	0.59	Medium
Provide an example	0.51	Medium
Classifying	0.85	High
Drawing inferences	0.84	High
Compare	0.67	Medium
Average	0.69	Medium

Based on Table 9, the greatest improvement occurred in the classifying indicator (0.85), followed by drawing inferences (0.84), comparing (0.69), and interpreting (0.59), while the lowest achievement was in the providing examples indicator (0.51). The allocation of conceptual comprehension achievement across each indicator is shown in Figure 1.

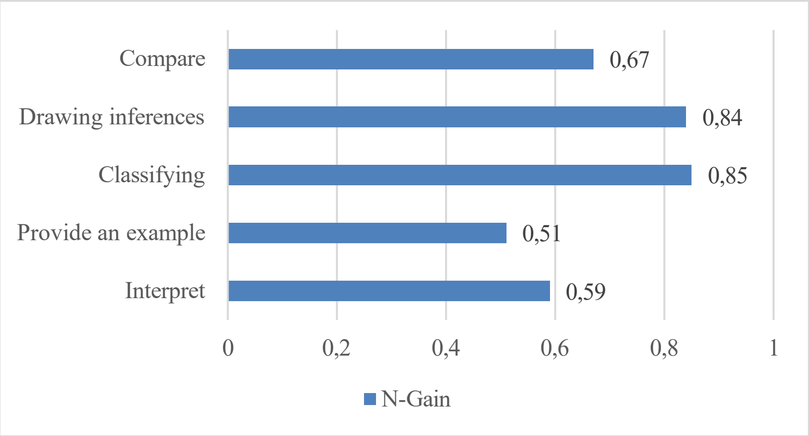

Figure 1. Histogram of N-Gain Values for Each Indicator

DISCUSSION

This study shows that implementing the discovery learning model, supported by virtual laboratories and hands-on activities, led to a notable improvement in junior high school students' conceptual understanding. This is evidenced by a moderate N-Gain value (0.69) and a statistically significant paired-samples t-test. These findings support the constructivist view that conceptual understanding develops optimally when students are actively involved in discovering, testing, and verifying concepts through meaningful learning experiences.

Based on Figure 1, the largest improvement was in the classification indicator with an N-gain value of 0.85. This finding indicates that discovery learning, supported by JavaLab and hands-on activities, is highly effective in developing students' ability to group concepts based on characteristics and relationships. During the learning process, students not only learn about work and energy but also directly observe changes in variables through JavaLab simulations and verify them through practical activities (Fitriana et al., 2022). This finding aligns with Research (Komariah & Jayanti, 2022), which reported that the discovery learning model significantly improves students' concept classification abilities by actively engaging them in building their own knowledge structures.

The inference-drawing indicator achieved a high N-Gain (0.84), indicating that students were able to infer causal relationships and draw logical conclusions from observational and experimental data. The combination of virtual laboratories and hands-on learning enhances knowledge acquisition, thereby strengthening students' data interpretation and evidence-based reasoning skills (Bazie et al., 2024; Tokatlidis et al., 2024). This conclusion is supported by Research (Azhar et al., 2023) showing that learning through discovery, assisted by virtual laboratories, significantly improves the ability to analyse experimental data and draw evidence-based conclusions. Other Research also indicates that discovery learning, when accompanied by practical activities, can improve students' ability to draw inferences because they are directly involved in the scientific process (Amelia et al., 2025).

Furthermore, the comparison indicator reached 0.67, which is categorised as moderate. A moderate score on this indicator indicates that some students still experience difficulties conducting in-depth conceptual comparisons, especially when linking simulation results to real-world phenomena (Siahaan & Sihotang, 2023). This conclusion is backed by Research (Khairuna et al., 2021) that found that the combination of virtual laboratories and practical activities improved conceptual comparison analysis skills. However, the improvement was in the moderate category. Furthermore, the interpretation indicator reached a value of 0.59, which is categorised as moderate. This indicates that students improved their ability to understand and interpret data, graphs, and observed phenomena, although the improvement was not optimal. Most students still require ongoing guidance and practice in reading and interpreting experimental data (Dafira & Widodo, 2021a). This conclusion is backed by Research (Wanabuliandari et al., 2025), which demonstrated that skills in interpretation (interpreting graphs, data, and phenomena) improved more slowly than inference and classification, because students required explicit practice in reading and interpreting experimental data. Most students tend to focus on the final results of experiments without deeply linking the data's meaning to theoretical concepts (Dianti et al., 2023).

The indicator providing examples had the lowest increase at 0.51, which was categorised as moderate. This indicator tends to increase less than other indicators because students have difficulty transferring learned concepts to concrete examples or everyday life contexts (Nurfathonah et al., 2024). This discovery aligns with previous studies (Janah & Hidayati, 2025). The discovery showed that students often partially understand concepts but are unable to provide appropriate examples. Discovery learning models will be more effective in improving conceptual understanding if accompanied by contextual questions, case studies, or problem-based assignments that require students to provide real-life examples of the concepts being learned (Jariyah & Efendi, 2024b).

In general, the implementation of applied learning positively enhances students' conceptual skills. The integration of JavaLab as a virtual laboratory is crucial to successful learning because it provides interactive visualizations of abstract concepts such as work and energy. This is consistent with the findings of Alnaser & Forawi (2024), who emphasised that virtual laboratories impact student motivation, conceptual understanding, and engagement by providing a safe, flexible environment for exploration. Furthermore, the combination of virtual laboratories and hands-on activities provides a more comprehensive learning experience. JavaLab simulations help students build an initial understanding of abstract concepts, while hands-on activities allow students to confirm and validate that understanding through direct experience. This discovery aligns with previous studies, Tokatlidis et al. (2024b), which found that combining virtual laboratories and hands-on activities yielded higher learning outcomes than either approach alone. Students found it easier to verify concepts through physical hands-on experience after understanding the concept descriptions in JavaLab.

The findings of this study indicate that integrating JavaLab-assisted discovery learning with hands-on activities is a highly relevant approach to addressing the challenges of science learning in schools with limited laboratory facilities. Learning not only results in significant improvements in conceptual understanding but also builds a deeper, more contextual learning experience that aligns with the demands of 21st-century competencies. Furthermore, this study's results confirm that interactive learning technology can serve as a bridge between abstract Material and students' concrete experiences, thereby facilitating the development of conceptual understanding. An important implication of this study is the need for science teachers to adopt a discovery-based approach that integrates digital media and practical activities in a balanced manner. This hybrid approach has the potential to improve the quality of science learning across schools, while also providing teachers with innovative alternatives for planning more interactive learning activities.

Research Limitations

This study has several methodological limitations. Initially, the research design used a single-group pretest-posttest design without a control group, making it impossible to attribute the change in conceptual understanding solely to the application of the discovery learning model alongside JavaLab and practical activities. Second, the comparatively small sample size (n = 23) and the study's limited context (one school) may limit the generalizability of the findings. Therefore, future studies are encouraged to use an experimental or quasi-experimental design with a control group and to increase sample size and diversity to yield findings with greater inferential accuracy and generalizability.

4. CONCLUSION

This study shows that integrating discovery learning models, supported by virtual laboratories and hands-on activities, significantly enhances students' conceptual understanding. From a theoretical standpoint, the results of this study assist the constructivist and discovery-based learning framework by demonstrating that integrating discovery learning, supported by virtual laboratories (JavaLab), with hands-on activities effectively facilitates students' conceptual understanding. The combination of these two approaches allows students to build concepts through visual exploration, data analysis, and empirical verification, so that learning is not only representational, but also contextual and meaningful. Thus, this study enriches the study of science learning by emphasising the role of hybrid approaches in strengthening conceptual understanding in abstract materials such as work and energy. Instructionally, the findings of this Research suggest that JavaLab is applicable for use as an alternative laboratory, especially in schools with limited practicum facilities, and that it should be integrated with hands-on activities in a planned manner so that learning does not stop at simulation alone but instead strengthens students' conceptual understanding. These findings are expected to serve as a reference for teachers and researchers in creating science education that is more interactive, adaptive, and oriented towards strengthening students' conceptual understanding. Future Research is recommended to use a quasi-experimental or true experimental design with a control group to strengthen causal conclusions. Studies with larger and more diverse samples are also encouraged to improve the generalizability of findings. Additionally, future researchers may apply this hybrid approach to other abstract science topics, such as electric circuits, optics, and fluid dynamics. Further investigation into students' long-term conceptual retention and the impact of this approach on higher-order thinking skills is also suggested.

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