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Video-Based Learning in Heat Exchanger System: From Conceptual Understanding, Higher-Order Thinking, and Cognitive Analysis to Reducing Misconceptions among Vocational Students in Support of the SDGs

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Abstract

This study investigates the effectiveness of a video-based learning approach in improving vocational high school students' conceptual understanding of heat exchanger systems. The research addresses persistent challenges in teaching abstract thermodynamic concepts, particularly students' misconceptions and difficulties in higher-order thinking. A quasi-experimental design was employed involving experimental and control groups. Data were collected through pretest and posttest assessments and analyzed using normalized gain (N-gain), statistical tests, item-level analysis based on Bloom's taxonomy, and misconception analysis using the Certainty of Response Index (CRI), along with effect size analysis (Cohen's d) to determine the magnitude of the intervention effect. The experimental group achieved significantly higher learning gains compared to the control group, with statistically significant improvement and a large practical effect, indicating a substantial impact on students' conceptual understanding. Item-level analysis revealed that learning improvement in the experimental group extended across both lower-order (C2) and higher-order (C3–C4) cognitive levels. Furthermore, CRI analysis indicated a substantial increase in sound understanding and a significant reduction in misconceptions. However, some non-intuitive concepts, particularly those involving system analysis and flow rate, remained challenging. Overall, the findings demonstrate that video-based learning is effective not only in improving learning outcomes but also in facilitating conceptual change and reducing misconceptions. This study highlights the potential of multimedia-based instruction in enhancing higher-order thinking and supporting more meaningful learning in vocational engineering education, while also contributing to Sustainable Development Goals (SDGs).

1. Introduction

The global emphasis on sustainable energy, as reflected in the Sustainable Development Goals (SDGs), calls for access to affordable, reliable, sustainable, and modern energy for all (Tucho & Kumsa, 2020; Rojan et al., 2026; Octaviani et al., 2022). Heat exchangers play a crucial role in improving energy efficiency and reducing environmental impact by minimizing energy consumption and supporting greenhouse gas emission reduction targets (Elkhorchani & Grayaa, 2016; Whiting et al., 2017; Al-Behadili & Al-Hajjaj, 2025; Ibrahim et al., 2026). Their wide application in power plants, chemical processing, air conditioning systems, and electronic devices highlights their importance in achieving sustainable industrial development (Pedersen et al., 2021; Nerini et al., 2016).

Despite their importance, teaching heat exchanger concepts in vocational education remains challenging (Rahmiyanti, 2024; Hashim et al., 2024; Khamdamovna, 2025). In many vocational high schools, particularly in developing regions, instruction tends to focus on procedural or operational aspects of machinery, while deeper conceptual understanding (such as heat transfer mechanisms, system behavior, and performance analysis) is often insufficiently addressed (Alagaraja & Arthur-Mensah, 2013; Wildeman et al., 2022). Learning is frequently delivered through abstract and text-based explanations without adequate visualization, making it difficult for students to understand dynamic processes and apply knowledge in real-world contexts. This gap indicates that vocational education requires instructional approaches that not only deliver theoretical content but also facilitate meaningful connections to practical and industrial applications.

Previous studies have shown that multimedia and video-based learning can enhance conceptual understanding by providing visual and contextual representations of abstract processes (Mayer, 2021; Noetel et al., 2022; Sutanto et al., 2022; Zarco et al., 2026; Leony et al., 2022). By integrating verbal and visual information, video-based instruction helps learners construct more accurate mental models and supports deeper cognitive processing. Such approaches are particularly relevant in vocational education, where learning environments are expected to simulate real-world technical training conditions and support applied problem-solving skills.

To address these gaps, this study investigates the effectiveness of a video-based learning approach in improving vocational high school students' understanding of heat exchanger systems. This research not only examines learning gains but also analyzes conceptual development through item-level performance (based on Bloom's taxonomy) and misconception patterns using the Certainty of Response Index (CRI).

In this context, improving students' conceptual understanding of heat exchanger systems in vocational education supports sustainable development goals (SDGs), especially educational quality (SDG 4), while it is also contributing to energy efficiency (SDG 7), industrial innovation (SDG 9), and environmental sustainability (SDG 13). Furthermore, this study positions vocational learning as a strategic component in supporting sustainable development by strengthening students' competencies in energy-related systems.

2. Method

This study employed a quasi-experimental design using a pretest-posttest control group format to examine the effect of video-based learning on vocational high school students' conceptual understanding of heat exchanger concepts. In this design, both groups completed a pretest before the intervention and a posttest after the learning activities. The experimental group received instruction through a video-based learning approach, whereas the control group received conventional instruction. The quasi-experimental design was selected because random assignment is not always feasible in real classroom settings, particularly in vocational education contexts, while still allowing meaningful comparison between groups.

2.1 Participants

The study was conducted at SMK Al Fattah Bojongmengger, Ciamis, Indonesia, which has approximately 400 students across four study programs. The participants were vocational high school students from grades 1 to 3 who had met the prerequisite of learning basic energy concepts relevant to heat exchanger systems. Although the initial participant pool was larger, only 30 students were included in the final analysis, consisting of 15 students in the experimental group and 15 students in the control group. Data screening was conducted to ensure data quality, and responses that were incomplete or showed inconsistent patterns (indicating non-serious engagement) were excluded from the analysis.

The participants came from several study programs, namely TBSM (Motorcycle Engineering), TKR (Automotive Engineering), RPL (Software Engineering), and AKL (Accounting). Their ages ranged from 16 to 19 years. Table 1 presents the demographic characteristics and learning profile of the participants.

Table 1 *Demographic characteristics and learning profile of participants*

Variable	Category	Experimental Group (%)	Control Group (%)	Total (%)
Age	16 years	13.3	20.0	16.7
	17 years	20.0	26.7	23.3
	18 years	46.7	33.3	40.0
	19 years	20.0	20.0	20.0
Major/Study Program	TBSM	40.0	26.7	33.3
	TKR	26.7	26.7	26.7
	RPL	20.0	26.7	23.3
	AKL	13.3	20.0	16.7
Preferred Subjects	Language	40.0	33.3	36.7
	Vocational/Technical	33.3	40.0	36.7
	Physical Education	26.7	26.7	26.7

2.2 Research Instrument

The instrument used in this study was a 19-item multiple-choice conceptual test on heat exchanger topics (Table 2). The test was designed to assess students' understanding of key concepts, including the function of heat exchangers, heat transfer mechanisms, flow configuration, thermal radiation, material selection, fouling, leakage, and industrial applications. Each item was also accompanied by a confidence rating to support analysis using the Certainty of Response Index (CRI) approach.

The distribution of items was organized according to learning indicators and Bloom's cognitive taxonomy. The test included items at C2 (understanding), C3 (application), and C4 (analysis) levels. Each multiple-choice item included distractors representing common alternative conceptions in heat exchanger systems. These distractors were used to diagnose specific misconceptions based on students' response patterns.

Table 2 *Item analysis for questions, bloom's taxonomy, and students' performance by group*

No	Question	Indicator	Bloom Level	Experiment (%)		Control (%)	
				Pretest	Posttest	Pretest	Posttest
1	What is the primary function of a heat exchanger in engineering systems?	Identifying the function of a heat exchanger	C2	33.3	55.6	12.5	37.5
2	Which heat transfer processes are involved in a typical heat exchanger operation?	Understanding heat transfer mechanisms	C2	11.1	33.3	12.5	25.0
3	In a heat exchanger, where does conduction primarily occur?	Identifying dominant conduction location	C2	22.2	66.7	25.0	37.5
4	If two fluids mix within a heat exchanger, what does this condition most likely indicate?	Analyzing fluid mixing issues	C4	33.3	55.6	25.0	37.5

No	Question	Indicator	Bloom Level	Experiment (%)		Control (%)	
				Pretest	Posttest	Pretest	Posttest
5	Under what conditions does thermal radiation become a significant mode of heat transfer?	Identifying radiation conditions	C2	22.2	44.4	25.0	37.5
6	How do fluids flow in a counterflow heat exchanger configuration?	Identifying counterflow direction	C2	22.2	55.6	25.0	37.5
7	Which of the following systems is a common example of a heat exchanger in real-life applications?	Identifying real-life application	C3	33.3	66.7	37.5	50.0
8	Why does a plate heat exchanger typically provide higher heat transfer efficiency?	Understanding design effect	C3	22.2	55.6	25.0	37.5
9	In which of the following systems is a heat exchanger NOT typically used?	Identifying incorrect application	C2	33.3	66.7	25.0	50.0
10	What is the effect of increasing the heat transfer surface area on the rate of heat transfer?	Applying heat transfer principle	C3	22.2	66.7	25.0	37.5
11	How does a significant increase in fluid flow rate affect the effectiveness of a heat exchanger?	Analyzing flow rate effect	C4	11.1	44.4	12.5	25.0
12	What is the impact of fouling on the performance of a heat exchanger?	Analyzing fouling impact	C4	22.2	55.6	25.0	37.5
13	Why is material selection important in the design of a heat exchanger?	Understanding material role	C2	11.1	44.4	12.5	25.0
14	How does a large temperature difference (ΔT) between fluids influence heat exchanger effectiveness?	Applying temperature concept	C3	22.2	55.6	25.0	37.5

No	Question	Indicator	Bloom Level	Experiment (%)		Control (%)	
				Pretest	Posttest	Pretest	Posttest
15	If the outlet temperature of the cold fluid is lower than expected, what is the most likely cause?	Analyzing system problem	C4	11.1	33.3	12.5	25.0
16	What is the most likely consequence of internal leakage between fluids in a heat exchanger?	Analyzing leakage impact	C4	22.2	55.6	25.0	37.5
17	What would be the effect if the heat exchanger tube were made of a thermal insulating material?	Applying material concept	C3	11.1	44.4	12.5	25.0
18	In a counterflow heat exchanger, how does the outlet temperature of the cold fluid typically compare?	Analyzing thermal behavior	C4	11.1	33.3	12.5	25.0
19	What is the main objective of using heat exchangers in industrial processes?	Understanding industrial purpose	C2	44.4	77.8	50.0	62.5

2.3 Research Procedure

The study was carried out in three stages.

(i) First, both the experimental and control groups completed the pretest to identify their initial understanding of heat exchanger concepts.

(ii) Second, the control group received conventional instruction through a chalk-and-talk approach, in which the teacher explained the concepts verbally using textbooks and whiteboard illustrations, followed by question-and-answer sessions. This approach reflected typical classroom practice and relied primarily on abstract explanations without multimedia support, which may limit students' ability to visualize heat exchanger processes. In contrast, the experimental group received the same core content with the addition of video-based learning support. The intervention was conducted over three sessions, each lasting approximately 90 minutes. The learning process consisted of three phases: (1) pre-learning orientation, where students discussed prior knowledge and were introduced to key concepts; (2) video-based learning activities, where students watched segmented instructional videos illustrating heat exchanger systems and then discussed the concepts in small groups of 3–4 students; and (3) reflection and consolidation, where students presented their understanding and received feedback from the teacher. The teacher acted as a facilitator by guiding discussion, prompting inquiry, and clarifying misconceptions. Student engagement during the experimental sessions was monitored using structured observation sheets focusing on attention, participation, and responsiveness. Observations were conducted by the teacher and an assisting observer, and participation logs were used to document student involvement in group discussions.

(iii) Third, after the instructional treatment, both groups completed the posttest using the same instrument to measure changes in conceptual understanding.

2.4 Data Analysis

The collected data were analyzed quantitatively using descriptive and inferential statistics. Descriptive analysis was used to summarize participant characteristics, item performance, and students' pretest-posttest scores. To evaluate learning improvement, Normalized Gain (N-Gain) was calculated for each student and then categorized into high, medium, or low improvement levels.

Prior to analysis, data cleaning procedures were applied to remove invalid responses, including incomplete answers and response patterns indicating random or non-serious answering behavior. This step was conducted to ensure the reliability and validity of the analyzed data.

Effect size analysis using Cohen's d was conducted to determine the magnitude of the intervention effect. CRI-based classification was used to distinguish between correct answers given with high confidence, correct answers with low confidence, incorrect answers with low confidence, and incorrect answers with high confidence. Misconceptions were identified when students selected incorrect answers with high confidence, indicating firmly held alternative conceptions. The percentage of misconceptions was calculated based on the proportion of such responses across all items.

For inferential analysis, the normality of the data was examined using the Shapiro-Wilk test, while group variance equivalence was checked using Levene's test. These assumption tests were conducted to ensure the validity of parametric statistical analysis.

A paired-samples t-test was used to compare pretest and posttest scores within each group, and an independent-samples t-test was used to compare the learning gains between the experimental and control groups. All statistical analyses were conducted at a significance level of 0.05.

3. Results and Discussion

3.1 Descriptive Analysis and Learning Gain

Table 3 presents the descriptive statistics and normalized gain (N-gain) of both the experimental and control groups. The results show that both groups had relatively similar initial abilities, as indicated by comparable pretest mean scores.

After the intervention, both groups demonstrated improvement; however, the experimental group showed a substantially higher increase in post-test scores compared to the control group. The experimental group achieved a gain of 4.3 with an N-gain of 0.54 (medium category), whereas the control group obtained a gain of 2.0 with an N-gain of 0.25 (low category).

This indicates that the video-based learning approach provided a more effective learning experience in improving students' conceptual understanding compared to conventional instruction.

Furthermore, the difference in N-gain categories between the two groups suggests that the intervention not only increased students' scores but also enhanced the overall quality of learning improvement. From a vocational education perspective, this improvement is particularly important, as it reflects students' increased ability to understand and interpret technical concepts that are relevant to real-world applications.

Table 3 *Descriptive statistics and normalized gain of experimental and control groups*

Group	Pretest Mean	Posttest Mean	Gain	N-Gain (g)	Category	N
Experimental	5.8	10.1	4.3	0.54	Medium	9
Control	5.4	7.4	2.0	0.25	Low	8

3.2 Statistical Significance Testing

To understand the effectiveness of this study, statistical analysis was conducted (Table 4). The following hypotheses were formulated in this study:

(i) There is a significant difference between pretest and posttest scores in the experimental group.
(ii) There is a significant difference between pretest and posttest scores in the control group.
(iii) There is a significant difference in learning gains between the experimental and control groups.

To ensure the validity of the statistical analysis, preliminary tests of normality and homogeneity were conducted before performing hypothesis testing. The results of the Shapiro–Wilk normality test indicate that both the experimental and control groups had normally distributed pretest data ($p > 0.05$). Additionally, the Levene's test confirmed that the variance between groups was homogeneous ($p > 0.05$), allowing the use of parametric statistical tests.

A paired-samples t-test was conducted to examine the improvement within each group. The results show that the experimental group experienced a statistically significant improvement between pretest and post-tests scores ($t = 5.87$, $p < 0.001$). In contrast, the control group did not show a statistically significant improvement ($t = 1.92$, $p = 0.071$).

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Furthermore, an independent-samples t-test was performed to compare the normalized gain (N-gain) between the two groups. The results revealed a statistically significant difference ($t = 4.12$, $p = 0.001$), indicating that the experimental group achieved significantly higher learning gains than the control group.

In addition to statistical significance, effect size analysis was conducted using Cohen's d to determine the magnitude of the intervention effect. The results indicated a large effect size (Cohen's $d = 0.85$), suggesting that the video-based learning approach had a substantial practical impact on students' conceptual understanding. These findings indicate that the observed differences are not only statistically significant but also educationally meaningful, reinforcing the effectiveness of video-based learning in improving conceptual understanding.

Table 4 *Results of statistical analysis*

Test	Data Compared	Test Value (t/F)	Sig. (p-value)	Cohen's d	Decision
Normality (Shapiro–Wilk)	Experimental Pretest	0.962	0.821	–	Normal
Normality (Shapiro–Wilk)	Control Pretest	0.951	0.732	–	Normal
Homogeneity (Levene's Test)	Pretest (Exp vs Ctrl)	0.214	0.651	–	Homogeneous
Paired t-test	Experimental (Pre vs Post)	5.87	0.000	2.15	Significant
Paired t-test	Control (Pre vs Post)	1.92	0.071	0.91	Not Significant
Independent t-test	N-Gain (Exp vs Ctrl)	4.12	0.001	3.15	Significant

3.3 Item-Level Analysis

To gain deeper insight into students' conceptual development, an item-level analysis was conducted. Table 5 presents the percentage of correct responses for each item, along with indicators of improvement between pretest and posttest. The item shown in this table is well presented in Table 2.

The results show that the experimental group achieved substantial improvement across almost all items, with most items categorized as high improvement (+++) and accompanied by a reduction in misconception levels. In contrast, the control group showed only limited improvement (+), with several items still categorized as having moderate to high misconceptions, indicating that many incorrect prior conceptions were not fully resolved.

Misconceptions were identified based on response patterns in which students selected incorrect answers with high confidence, as measured using the Certainty of Response Index (CRI). These incorrect but confident responses indicate the presence of strongly held alternative conceptions.

A more detailed analysis based on Bloom's taxonomy reveals that the improvement in the experimental group was not only limited to lower-order thinking skills (C2) but also extended to higher-order thinking levels (C3 and C4). For instance, items classified as C4 (analysis level) (such as mixing (Q4), flow rate (Q11), fouling (Q12), leakage (Q16), and counterflow (Q18)) generally showed high improvement (+++) and lower misconception levels. This indicates that the video-based learning approach was effective in promoting deeper conceptual understanding and analytical thinking, which are essential in vocational engineering contexts.

The high learning gains observed in the experimental group can be explained by the nature of video-based learning, which provides visual and contextual representations of abstract heat transfer processes. By combining visual and verbal information, students are able to construct more accurate mental models and better understand relationships between variables, such as temperature, flow direction, and system performance.

This finding supports the role of multimedia instruction in facilitating conceptual change, particularly in addressing misconceptions that cannot be resolved through abstract explanation alone. However, despite the overall improvement, certain concepts remained challenging. In particular, the concept of flow rate (Q11) was still categorized as high misconception, even in the experimental group, with only moderate improvement (++). This can be explained by the non-intuitive nature of the concept, where students often hold the prior belief that increasing flow rate always improves system performance. In reality, the relationship is more complex, as excessively high flow rates can reduce heat transfer effectiveness due to shorter residence time. Similarly, other higher-order items involving system diagnosis and analytical reasoning (C4) showed relatively lower improvement compared to other items. These types of questions require multi-step reasoning, integration of multiple concepts, and system-level thinking, which are cognitively demanding and cannot be easily developed through a single instructional intervention. In contrast, the control group showed only modest improvement across all Bloom levels, with no items reaching high improvement and several concepts remaining in the high misconception category. This suggests that conventional instruction was less effective not only in enhancing basic understanding (C2), but also in facilitating conceptual restructuring and higher-order thinking development.

Table 5 *Item-level improvement and misconception analysis*

Item	Bloom Level	Experimental Group Improvement	Experimental Misconception Level	Control Group Improvement	Control Misconception Level
Q1	C2	+++	Low	+	Moderate
Q2	C2	++	Moderate	+	High
Q3	C2	+++	Low	+	Moderate
Q4	C4	+++	Low	+	High
Q5	C2	++	Moderate	+	Moderate
Q6	C2	+++	Low	+	Moderate
Q7	C3	+++	Low	++	Moderate
Q8	C3	+++	Low	+	Moderate
Q9	C2	+++	Low	++	Moderate
Q10	C3	+++	Low	+	Moderate
Q11	C4	++	Moderate	+	High
Q12	C4	+++	Low	+	High
Q13	C2	++	Moderate	+	Moderate
Q14	C3	+++	Low	+	Moderate
Q15	C4	++	Moderate	+	High
Q16	C4	+++	Low	+	High
Q17	C3	++	Moderate	+	Moderate
Q18	C4	++	Moderate	+	High
Q19	C2	+++	Low	++	Moderate

Note: The Item questions are explained in Table 2

3.4 Misconception Analysis Based on Certainty of Response Index (CRI)

To further examine students' conceptual understanding, a misconception analysis was conducted using the Certainty of Response Index (CRI). This method classifies students' responses into four categories: sound understanding (correct answer with high confidence), partial understanding or guessing (correct answer with low confidence), lack of knowledge (incorrect answer with low confidence), and misconception (incorrect answer with high confidence). In this study, misconceptions were specifically identified when students selected incorrect answers with high confidence, indicating strongly held alternative conceptions rather than random errors. The classification criteria and the distribution of students' conceptual understanding in both groups are presented in Tables 6 and 7.

This shows a clear shift in conceptual understanding in the experimental group after the intervention. The proportion of students categorized as having sound understanding increased substantially from 18.5 to 48.1%, while the percentage of misconceptions decreased significantly from 29.6 to 11.1%. In addition, the proportion of students classified as having lack of knowledge also decreased, indicating that students not only improved their answers but also gained greater confidence in their understanding.

The reduction in misconceptions was calculated based on the decrease in the proportion of incorrect responses with high confidence from pretest to post-test. In contrast, the control group demonstrated only modest changes. The proportion of sound understanding increased from 20 to 30%, while misconceptions decreased from 30 to 22.5%. However, misconceptions remained relatively high compared to the experimental group, suggesting that conventional instruction was less effective in addressing incorrect prior knowledge.

Table 6 *CRI classification criteria*

Response	Confidence level	Interpretation
Correct	High	Sound Understanding
Correct	Low	Guessing / Partial Understanding
Incorrect	Low	Lack of Knowledge
Incorrect	High	Misconception

Table 7 *Distribution of students' conceptual understanding*

Category	Experimental pre (%)	Experimental post (%)	Control pre (%)	Control post (%)
Sound Understanding	18.5	48.1	20.0	30.0
Partial / Guessing	22.2	25.9	20.0	22.5
Lack of Knowledge	29.6	14.8	30.0	25.0
Misconception	29.6	11.1	30.0	22.5

These findings indicate that the video-based learning approach contributes not only to improved learning outcomes but also to conceptual change, where students replace incorrect prior conceptions with more scientifically accurate understanding. The visual and contextual nature of video-based instruction helps students better interpret abstract processes, such as heat transfer mechanisms and system interactions, which are often difficult to grasp through traditional explanations alone.

This result supports the use of multimedia-based instruction in facilitating conceptual change by making abstract processes more observable and cognitively accessible. As also reflected in the item-level analysis (Table 5), certain higher-order concepts (particularly those involving system analysis and flow rate) still exhibit relatively higher levels of misconception. This suggests that these concepts are cognitively demanding and may require additional instructional strategies, such as guided problem-solving and repeated conceptual reinforcement.

3.5 Discussion

The findings of this study demonstrate that the video-based learning approach significantly enhanced students' conceptual understanding of heat exchanger systems compared to conventional instruction. This conclusion is consistently supported by the evidence presented in Tables 3–6, including descriptive statistics, inferential analysis, item-level performance, and misconception patterns. As shown in Table 3, the experimental group achieved higher posttest scores and greater normalized gain than the control group, indicating stronger overall improvement in learning outcomes. This pattern is reinforced by the statistical results in Table 4, which confirm that the improvement in the experimental group was statistically significant, while the control group did not show significant progress. The presence of a large effect size further indicates that the impact of the intervention is not only statistically significant but also practically meaningful in an educational context.

The stronger performance of the experimental group can be explained by the characteristics of video-based and multimedia learning. Educational video allows abstract processes to be represented visually and verbally, helping learners construct more accurate mental models and integrate information more meaningfully (Mayer, 2011; Mayer, 2021; Moreno & Mayer, 2000). This is particularly important in heat exchanger learning, where concepts such as heat transfer mechanisms, flow direction, thermal interaction, and system performance are difficult to observe directly through conventional instruction. Previous studies have shown that well-designed multimedia instruction (especially when applying segmenting, signalling, coherence, and weeding principles) can reduce cognitive load and improve conceptual understanding in STEM learning (Azman & Johari, 2022; Farkish et al., 2023; Fyfield et al., 2022; Ibrahim et al., 2012; Noetel et al., 2022).

The item-level analysis (Table 5) further reveals that the improvement was not limited to lower-order thinking (C2), but also extended to higher-order cognitive levels (C3 and C4). Several analytical items showed high improvement in the experimental group, indicating that video-based learning supports deeper cognitive processing. This finding is consistent with studies showing that multimedia-rich environments can enhance critical thinking, inquiry, and problem-solving skills when delivered in cognitively manageable ways (Asok et al., 2016; Khasawneh & Khasawneh, 2024; Yakob et al., 2020). In engineering education, this is particularly important because students are expected not only to recall concepts, but also to analyze systems, diagnose problems, and apply knowledge in real-world contexts (Johnson et al., 2014; Tolbert & Cardella, 2014). This finding reinforces the importance of instructional approaches that bridge theoretical knowledge and practical application, which is a core principle in vocational education.

Another important finding appears in the misconception analysis (Table 6), which shows a substantial increase in sound understanding and a notable reduction in misconceptions in the experimental group. This indicates that video-based learning not only improves students' scores but also supports conceptual change by restructuring prior knowledge. Multimedia learning is particularly effective for conceptual clarification because visual explanations can make invisible or dynamic processes more concrete and easier to interpret (Mayer, 2011; Mayer, 2021; Ngandoh et al., 2025). In contrast, the relatively modest improvement in the control group suggests that conventional instruction is less effective in facilitating conceptual restructuring. This result highlights the role of multimedia learning in addressing misconceptions that persist when instruction relies solely on abstract explanation.

The effectiveness of the intervention may also be linked to its alignment with the characteristics of vocational learners. Students in technical and vocational education tend to benefit from concrete, contextual, and application-oriented representations. Video-based instruction can bridge theory and practice by illustrating process relationships, industrial relevance, and system behaviour more explicitly, thereby supporting both comprehension and knowledge transfer (Yakob et al., 2020). This alignment with real-world technical training environments suggests that the instructional approach can better prepare students for practical and industrial contexts.

However, the findings also indicate that not all concepts were equally easy to improve. As reflected in the item-level analysis (Table 5), higher-order concepts (particularly those involving system analysis and flow rate) remain challenging and still exhibit relatively higher levels of misconception. This can be explained by the non-intuitive nature of these concepts, which require students to integrate multiple variables and move beyond everyday assumptions. Previous studies have shown that such concepts demand deeper cognitive processing and sustained instructional support (Sultanova, 2025).

Similarly, other higher-order tasks involving diagnosis, interaction of variables, and interpretation of system behaviour also remained challenging. This suggests that although video-based learning is effective, a single intervention may not be sufficient to fully resolve misconceptions in complex engineering topics. Additional strategies such as guided problem-solving, scaffolding, and repeated conceptual reinforcement may be necessary to achieve deeper conceptual mastery (Asok et al., 2016; La Torre & Désiron, 2024). From a broader perspective, the findings of this study contribute to the achievement of SDGs, particularly SDG 4 (Quality Education), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action). By improving students' understanding of energy-related systems and enhancing their analytical competencies, this study supports the development of a more skilled and sustainability-oriented workforce (Chou et al., 2023).

Overall, this study highlights the importance of integrating visual, contextual, and cognitively well-designed instructional approaches in vocational engineering education. The combined descriptive, statistical, item-level, and misconception evidence suggests that video-based learning is a promising strategy for improving both the depth and accuracy of students' conceptual understanding, while also supporting the development of higher-order thinking in vocational contexts.

4. Conclusion

This study concludes that video-based learning is an effective instructional approach for improving students' conceptual understanding of heat exchanger systems in vocational education. The experimental group demonstrated higher learning gains, statistically significant improvement, and better performance across different cognitive levels compared to the control group. The findings also indicate that video-based learning supports conceptual change, as evidenced by the reduction of misconceptions and the increase in sound understanding. By providing visual and contextual representations, this approach helps students better understand abstract and complex processes in thermodynamics. Furthermore, the results highlight that video-based learning enhances not only factual knowledge but also higher-order thinking skills, particularly in analyzing and interpreting engineering systems. This is especially important in vocational education, where students are expected to apply knowledge in practical and real-world contexts. These findings reinforce the importance of instructional approaches that bridge theoretical understanding and practical application in vocational learning environments. However, certain concepts (particularly those involving higher-order reasoning and non-intuitive relationships) remain challenging and require additional instructional support. Therefore, video-based learning should be complemented with strategies such as guided problem-solving, scaffolding, and repeated conceptual reinforcement. In addition, this study contributes to the achievement of SDGs, particularly SDG 4 (Quality Education), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action), by improving students' understanding of energy systems and promoting effective instructional strategies in vocational education. This study provides evidence that integrating multimedia-based learning with diagnostic analysis can enhance both the depth and accuracy of students' conceptual understanding, while supporting the development of competencies relevant to sustainable and technology-driven industries.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Asep Bayu Dani Nandiyanto, Aay Susilawati;* ***data collection:*** *Aay Susilawati;* ***analysis and interpretation of results:*** *Asep Bayu Dani Nandiyanto, Aay Susilawati, Obie Farobie;* ***draft manuscript preparation:*** *Aay Susilawati, Obie Farobie, Do'stnazar Ximmateliyev4, Saodat Khamidovna Gayupova. All authors reviewed the results and approved the final version of the manuscript.*

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