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Enhancing Students' Conceptual Understanding of Dynamic Fluids through Inquiry-Based Learning Integrated with Deep Learning Approach and Articulate StorylineMedia

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ABSTRACT

The rapid advancement of science and technology has increased the complexity of information and phenomena encountered by students, making conceptual understanding essential for physics learning. However, students experience difficulties in understanding fluid dynamics because the topic involves abstract concepts and their application to situations. Although Inquiry-Based Learning (IBL), deep learning principles, and digital media have demonstrated potential to support conceptual understanding, limited empirical studies have examined their integrated implementation in physics learning. Therefore, this study aimed to investigate the improvement in students' conceptual understanding of fluid dynamics through the integration of IBL, a deep learning approach, and Articulate Storyline. The study employed a one-group pretest-posttest experimental design involving 31 students from Class XI 9 IPA at SMAN 1 Sukoharjo. Students' conceptual understanding was measured using five multiple-choice and five essay questions. Results showed that the mean score increased from 42.94 to 79.67, with an average N-Gain of 0.61 (moderate). The Wilcoxon Signed-Rank Test indicated a significant difference between pretest and posttest scores ($Z = -4.860$, $p < 0.001$), while improvements were observed across all indicators. These findings indicate that integrating IBL with deep learning supported by Articulate Storyline promotes learning and provides an instructional alternative for teaching abstract concepts.

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INTRODUCTION

With the rapid development of science and technology, students now face increasingly complex phenomena and information, requiring deeper understanding in the learning process (Abidarda et al., 2024). In physics learning, this becomes even more crucial because physics is closely related to natural phenomena frequently encountered in everyday life.

Students should be required to understand the conceptual meaning behind each physical phenomenon. Conceptual understanding is the primary foundation of physics learning because it plays a crucial role in helping students connect scientific knowledge with real-life phenomena (Sari et al., 2021). Without a strong conceptual understanding, physics learning tends to focus on memorizing mathematical formulas and procedures. As a result, students are simply able to repeat the information presented without understanding the meaning of the concepts being learned, making them less able to explain physical phenomena scientifically or apply them to everyday life. This condition results in learning becoming less meaningful (Wulandari et al., 2023). Based on a student questionnaire at SMA N 1 Sukoharjo, physics teachers begin lessons by explaining the concept first, followed by formulas. However, 48.5% of students often memorize formulas rather than understand the meaning of physics concepts. Teaching and learning activities are still predominantly conducted through the direct instruction model, with limited opportunities for students to actively participate in learning activities, and students rarely conduct experiments or investigations to develop a deeper understanding of physics concepts.

Consequently, students struggle to connect physics concepts to everyday phenomena. They can only solve physics problems if they are similar to the example, but struggle if the problem format is different. Furthermore, 72.1% of students' physics grades do not reflect the effort they have put in. This situation makes it difficult for students to develop a meaningful understanding of concepts, and student learning evaluation results remain suboptimal. The preliminary findings were obtained through a needs analysis involving 68 Grade XI science students at SMA N 1 Sukoharjo using a structured questionnaire.

The questionnaire explored students' learning habits, conceptual understanding, perceptions of assessment, learning motivation, and the use of instructional media in physics learning. The percentages indicating that 48.5% of students tend to memorize formulas and that 72.1% perceive their grades as not reflecting their learning efforts were derived from this preliminary survey and were used to identify problems that require instructional improvement. The gap between learning demands and classroom practices demonstrates the need for a student-centered learning model that emphasizes the knowledge construction process. The Inquiry-Based Learning (IBL) model is relevant because it aligns with learning characteristics that require students to conduct investigations to discover and construct knowledge independently. Students are encouraged to propose hypotheses, conduct experiments, analyze results, and draw conclusions based on evidence (Yulianti et al., 2025).

IBL makes learning more meaningful for students and allows them to connect the knowledge they learn with everyday experiences (Aidoo, 2024). However, the implementation of IBL needs to be carried out more thoroughly, paying attention to the quality of students' learning experiences. Learning should be designed to promote mindful, meaningful, and joyful experiences so that students are actively engaged both cognitively and emotionally. This is in line with the Indonesian government's deep learning approach (Kemendikdasmen, 2025), which encourages students to construct knowledge through active learning experiences. In this approach, mindful learning emphasizes students' awareness of their own thinking processes during learning. Meaningful learning encourages students to connect new concepts with their prior knowledge and real-life experiences. Joyful learning promotes positive emotional engagement that increases students' motivation and persistence throughout the learning process (Feriyanto &Anjariyah, 2024). Interviews revealed that teachers frequently use whiteboards in the learning process compared to other learning media, resulting in low student motivation to understand physics material in depth. Students also easily lose focus when teachers only explain material on the board. A questionnaire found that 67.6% of students understood physics material more easily when using interactive learning media, while 91.1% of students felt the need for additional learning media that could facilitate a deeper and more meaningful understanding of physics concepts.

One engaging and interactive learning medium is Articulate Storyline (Majid and Kawuryana, 2023). This medium has been shown to increase student motivation due to its interactive display and features (Nurvitasari et al., 2025). Articulate Storyline provides a more enjoyable and meaningful learning experience, enabling students to improve their conceptual understanding. This also aligns with deep learning, which emphasizes a conscious, meaningful, and enjoyable learning process by integrating text, audio, video, and animation to accommodate various learning styles. Research conducted by Mediana et al. (2025) demonstrated that the IBL learning model can improve students' conceptual understanding.

Meanwhile, according to Musabbihan and Dantes (2024), the application of the IBL model combined with learning media has been shown to increase students' learning motivation. Deep learning can also improve the ability to understand concepts in depth. Based on previous research, the IBL models implemented have not integrated a deep learning approach and have not utilized interactive technology-based media such as Articulate Storyline, which has the potential to enhance students' learning experiences in a more meaningful way. Although previous studies have demonstrated the effectiveness of Inquiry-Based Learning and interactive learning media separately, limited research has integrated Inquiry-Based Learning, a deep learning approach, and Articulate Storyline within fluid dynamics instruction. This indicates a research gap in designing learning that simultaneously facilitates scientific inquiry, technology-supported interaction, and mindful, meaningful, and joyful learning experiences to enhance students' conceptual understanding.

Table 1. Research Gap Analysis of Previous Studies and the Present Study

Research	Inquiry-Based Learning	Articulate Storyline	Deep Learning Approach	Conceptual Understanding	Fluid Dynamics
Mediana Jr, N. L., Funa, A. A., & Dio, R. V. (2025)	✓	✘	✘	✓	✘
Sumarni, R. A., & Okyranida, I. Y. (2025)	✘	✘	✓	✓	✘
Suherly, T., Azizahwati, A., & Rahmad, M. (2023).	✘	✘	✘	✓	✓
Fatikhah, F. F., & Anggaryani, M. (2022).	✘	✓	✘	✘	✓

Table 1 shows that previous studies have examined Inquiry-Based Learning and interactive learning media independently, yet no study has integrated the Inquiry-Based Learning (IBL) model with a deep learning approach supported by Articulate Storyline in fluid dynamics instruction. This gap highlights the need for an instructional framework that combines scientific inquiry, technology-supported learning, and deep learning principles within a single learning process. Therefore, this study addresses the identified gap by integrating the IBL model, a deep learning approach, and Articulate Storyline to improve students' conceptual understanding of dynamic fluids. The novelty of this research lies in the systematic integration of these three components so that each phase of the IBL model not only develops students' scientific inquiry skills but also promotes mindful, meaningful, and joyful learning experiences. Through this integration, students are expected to construct concepts more actively, connect scientific knowledge with real-world phenomena, and achieve a deeper conceptual understanding of fluid dynamics. Accordingly, this study aims to determine the improvement in students' conceptual understanding of fluid dynamics through the implementation of the IBL model with a deep learning approach supported by Articulate Storyline as an interactive learning medium that encourages students to engage actively in the learning process.

METHODS

This study employed a quantitative approach using a pre-experimental method with a one-group pretest-posttest design. This method uses to examine the effect of IBL integrated with a deep learning approach and Articulate Storyline media on students' conceptual understanding of fluid dynamics. The study was conducted in the even semester of the 2025/2026 academic year at SMA Negeri 1 Sukoharjo, Pringsewu Regency, Lampung Province. The experimental procedure consisted of three stages: administering a pretest to determine students' initial conceptual understanding, implementing IBL integrated with mindful, meaningful, and joyful learning supported by Articulate Storyline, and administering a posttest to determine changes in conceptual understanding after the intervention. The IBL implementation followed six phases: orientation, problem formulation, hypothesis formulation, data collection, hypothesis testing, and drawing conclusions, with the deep learning principles incorporated into each phase and supported by interactive features of Articulate Storyline.

The population of this study comprised all students of Grade XI at SMA Negeri 1 Sukoharjo during the 2025/2026 academic year. The sample was selected using purposive sampling based on predetermined considerations relevant to the implementation of the instructional intervention. One class, consisting of 31 students from Grade XI-9, was selected as the experimental group. The selected students participated in the learning activities on fluid dynamics using IBL integrated with the deep learning approach and Articulate Storyline media. Thus, the study involved 31 students who completed both the pretest and posttest as the basis for evaluating changes in conceptual understanding. . The research design is presented in Table 2.

Table 2. Research Design

Classes	Pretest	Treat	Posttest
Eksperiment	O_1	X	O_2

Description

O_1 : a pretest is used to measure students' initial abilities before treatment is given.

X : treatment involves implementing the IBL model with a deep learning approach using Articulate Storyline media.

O_2 : posttest is used to measure students' abilities after treatment is given.

Data were collected using a conceptual understanding test administered before and after the intervention. The instrument consisted of 10 questions, comprising five multiple-choice questions and five essay questions, which were developed based on the conceptual understanding processes proposed by Anderson and Krathwohl, including interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining. The items were designed to assess students' conceptual understanding of fluid dynamics comprehensively across the targeted learning outcomes. Before administration, the instrument was subjected to validity and reliability testing to ensure that the items were appropriate for measuring students' conceptual understanding consistently. The validated and reliable instrument was subsequently administered as the pretest and posttest to obtain data on students' conceptual understanding before and after the intervention. The integration of IBL, deep learning, and Articulate Storyline are presented in Tables 3.

Table 3. Integration of IBL Phases, Deep Learning, and Articulate Storyline

IBL Phase	Student Activities	Deep Learning Implementation	Articulate Storyline Features
Orientation	Observe fluid dynamics phenomena.	Mindful: activate prior knowledge; Meaningful: relate phenomena to experience; Joyful: engage through contextual learning.	Phenomenon videos
Problem Formulation	Formulate research questions.	Mindful: identify problems critically; Meaningful: connect concepts; Joyful: interactive questioning.	Interactive questions.
Hypothesis Formulation	Develop hypotheses	Mindful: reason logically; Meaningful: apply prior knowledge; Joyful: collaborative discussion.	Guided hypothesis prompts.
Data Collection	Conduct investigations and collect data.	Mindful: observe systematically; Meaningful: construct knowledge from evidence; Joyful: active exploration.	Interactive simulations.
Hypothesis Testing	Analyze data and evaluate hypotheses.	Mindful: reflect on evidence; Meaningful: refine conceptual understanding; Joyful: receive immediate feedback.	Data analysis and feedback.
Drawing Conclusions	Draw conclusions and reflect.	Mindful: evaluate learning; Meaningful: integrate concepts; Joyful: appreciate learning outcomes.	Summary and reflective feedback.

The data analysis was conducted to determine changes in students' conceptual understanding before and after the implementation of the intervention. Descriptive statistics were first calculated using the mean scores of the pretest and posttest to describe students' achievement before and after the learning intervention. The magnitude of improvement in conceptual understanding was then determined using the Normalized Gain (N-Gain) index calculated from the pretest and posttest scores. Before hypothesis testing, a normality test was conducted to determine whether the data met the assumptions required for parametric analysis. Because the data were not normally distributed, the Wilcoxon Signed-Rank Test was employed at a significance level of 5% (α = 0.05) to determine whether there was a significant difference between students' pretest and posttest scores, and the analysis was also conducted for each conceptual understanding indicator.

RESULTS AND DISCUSSION

Results

Instrument validation was conducted before the instrument was used in the study. The validation process involved 32 respondents and utilized SPSS version 27.0 to determine the validity of each item in the instrument. In addition, the validation was conducted to ensure the instrument's reliability and confirm its suitability for collecting research data. The results of the validity tests for the multiple-choice and essay test instruments used to measure students' conceptual understanding are presented in Tables 4 and 5.

Table 4. Results of the Validity Test for the Multiple-Choice Question Instrument

Number Question	Conceptual Understanding Indicator	$r_{calculated}$	r_{table}	Notes
1	Interpreting	0.357	0.349	Valid
2	Exemplifying	0.548	0.349	Valid
3	Classifying	0.413	0.349	Valid
4	Summarizing	0.495	0.349	Valid
5	Comparing	0.413	0.349	Valid

Based on Table 4, all multiple-choice items obtained $r_{calculated}$ values higher than the r_{table} value of 0.349, indicating that all five items were valid and met the established validity criterion. The $r_{calculated}$ values ranged from 0.357 to 0.548, with the highest value obtained for the exemplifying indicator at 0.548 and the lowest value for the interpreting indicator at 0.357. These values indicate that each item had an adequate relationship with the conceptual understanding construct being measured, although the strength of the relationship varied across indicators. The item representing the exemplifying indicator showed the strongest correlation, whereas the interpreting item showed the weakest correlation; however, its value still exceeded the required validity threshold. This variation in correlation values does not affect the eligibility of the items because all items met the established validity criterion. Therefore, the five multiple-choice items presented in Table 4 were considered valid and suitable for measuring students' conceptual understanding of dynamic fluids.

In addition to multiple-choice questions, this study employed essay questions to obtain a more comprehensive assessment of students' conceptual understanding. The essay questions were developed based on conceptual understanding indicators, namely exemplifying, classifying, summarizing, inferring, and explaining. Each item was designed to assess students' ability to demonstrate and articulate their understanding of the concepts being studied. To determine whether the essay items appropriately measured the intended conceptual understanding indicators, a validity test was conducted, with the results presented in Table 5. The validity analysis was conducted to ensure that each item was relevant to the learning objectives and capable of representing the targeted conceptual understanding indicators. The results of this analysis provide a basis for determining the suitability of the essay questions for use as an instrument in assessing students' conceptual understanding of fluid dynamics.

Tabel 5. Results of the Validity Test for the Essay Question Instrument

Number Question	Conceptual Understanding Indicator	$r_{calculated}$	r_{table}	Notes
6	Exemplifying	0.817	0.349	Valid
7	Classifying	0.826	0.349	Valid
8	Summarizing	0.858	0.349	Valid
9	Inferring	0.836	0.349	Valid
10	Explaining	0.925	0.349	Valid

Based on Table 5, all five essay items obtained $r_{calculated}$ values higher than the r_{table} value of 0.349, indicating that all items satisfied the validity criterion (Hidayat, 2021). The $r_{calculated}$ values ranged from 0.817 to 0.925, reflecting a strong relationship between each essay item and the conceptual understanding indicators being assessed. The highest correlation was obtained for the explaining indicator with a value of 0.925, while the lowest correlation was found for the exemplifying indicator with a value of 0.817. These high correlation values indicate that each essay item had a strong relationship with the measured construct and was able to represent the targeted conceptual understanding indicators. Therefore, all essay items were considered valid and suitable for use in the pretest and posttest to measure students' conceptual understanding of dynamic fluids.

After the validity of the research instrument was confirmed, a reliability test was conducted to determine the consistency of the multiple-choice and essay instruments used in this study. Reliability was analyzed using Cronbach's Alpha coefficient, with higher values indicating greater internal consistency among the test items. The reliability analysis was performed separately for the multiple-choice and essay instruments, and the results are presented in Table 6. These results provide evidence that both instruments are sufficiently reliable for measuring students' conceptual understanding of fluid dynamics.

Table 6. Results of the Reliability Test for the Research Instruments

Instrument	Cronbach's Alpha	N of Items	Reliability Category
Multiple-choice test	0.481	5	Moderate (acceptable for preliminary research)
Essay test	0.904	5	Very high

As shown in Table 6, the multiple-choice instrument obtained a Cronbach's alpha coefficient of 0.481, indicating moderate internal consistency, while the essay instrument achieved a coefficient of 0.904, indicating very high reliability. The difference in reliability between the two instruments may be attributed to the characteristics of the test items, as the multiple-choice section consisted of only five items representing several conceptual understanding indicators, whereas the essay questions provided a more comprehensive assessment of students' understanding. Despite the difference in reliability coefficients, both instruments had previously met the validity criteria, demonstrating that they were appropriate for measuring the intended construct. These findings indicate that the multiple-choice and essay instruments complement each other in assessing students' conceptual understanding from different perspectives. Therefore, both instruments were considered suitable for use in the pretest and posttest to obtain a comprehensive evaluation of students' conceptual understanding of fluid dynamics (Sugiyono, 2013).

The pretest and posttest results were used to determine students' initial and final proficiency levels following the implementation of the IBL model with a deep learning approach supported by Articulate Storyline. The test instrument consisted of 5 multiple-choice questions and 5 essay questions designed based on conceptual understanding indicators. Scores for multiple-choice questions were assigned 1 for correct answers and 0 for incorrect answers, while essay questions used a scoring range of 0–5. The pretest and posttest data on students' conceptual understanding are presented in Table 7.

Table 7. Pretest and Posttest Results on Conceptual Understanding

Parameters	Pretest	Posttest
Lowest value	20	57.14
Highest value	68.57	95.23
Average value	42.94	79.67
Standard deviation	14.22	11.26

As presented in Table 7, students' conceptual understanding improved substantially after the implementation of the IBL model with a deep learning approach supported by Articulate Storyline. This improvement is reflected in the increase in the average score from 42.94 on the pretest to 79.67 on the posttest, indicating that students achieved a much better understanding of fluid dynamics concepts following the learning intervention. The increase in both the lowest score, from 20.00 to 57.14, and the highest score, from 68.57 to 95.23, suggests that learning gains occurred across students with different initial ability levels rather than being limited to high-achieving students. Furthermore, the decrease in the standard deviation from 14.22 to 11.26 indicates that students' posttest scores became more homogeneous, reflecting a more even distribution of conceptual understanding among the participants. These findings suggest that the learning intervention not only enhanced students' overall conceptual understanding but also reduced differences in learning outcomes across the class. Overall, the descriptive statistics provide initial evidence that integrating IBL, deep learning principles, and Articulate Storyline contributed to meaningful improvements in students' conceptual understanding of fluid dynamics before further verification through inferential statistical analysis.

The improvement in students' conceptual understanding was also analyzed for each conceptual understanding indicator to provide a more comprehensive evaluation of the learning outcomes. This analysis offers detailed information on students' performance across the different aspects of conceptual understanding measured in this study. Examining each indicator individually makes it possible to identify the aspects of conceptual understanding that showed the greatest and the least improvement after the learning intervention. The results of the indicator-based analysis are presented in Table 8.

Table 8. Improvement in each indicator of conceptual understanding

Concept Understanding Indicators	Pretest Average	Posttest Average	N-Gain	Category
Interpreting	87.09	93.54	0.50	Medium
exemplifying	57.52	75.80	0.43	Medium
classifying	55.37	77.95	0.51	Medium
summarizing	3225	76.88	0.66	Medium

comparing	38.71	83.87	0.74	High
inferring	14.19	80	0.77	High
explaining	15.48	69.67	0.64	Medium

Table 8 shows that all conceptual understanding indicators improved after the implementation of the IBL model with a deep learning approach supported by Articulate Storyline, as reflected by the positive N-Gain values across all indicators. The greatest improvement was observed in the inferring indicator (N-Gain = 0.77), followed by comparing (N-Gain = 0.74), indicating that the learning process provided strong support for students in analyzing relationships, interpreting evidence, and drawing conclusions from scientific phenomena. Moderate improvements were observed in the interpreting, exemplifying, classifying, summarizing, and explaining indicators, suggesting that students also strengthened their ability to understand, organize, and communicate conceptual knowledge throughout the learning activities. The variation in N-Gain values across the indicators indicates that the development of conceptual understanding was not uniform, as each indicator requires different cognitive processes and levels of reasoning. Nevertheless, improvements across all indicators demonstrate that the integration of IBL, deep learning principles, and Articulate Storyline supported students in developing conceptual understanding from basic interpretation to higher-order reasoning skills. Overall, these findings indicate that the implemented learning approach contributed to a comprehensive enhancement of students' conceptual understanding of fluid dynamics across all measured indicators.

The improvement in students' conceptual understanding was further examined using the Normalized Gain (N-Gain) index to determine the magnitude of learning gains achieved after the implementation of the learning intervention. The N-Gain analysis provides information on the extent to which students' conceptual understanding improved by considering both their initial and final levels of achievement. This analysis complements the descriptive comparison of the pretest and posttest by providing a standardized measure of learning improvement. The results of the N-Gain analysis are presented in Table 9.

Table 9. Average N-gain in conceptual understanding

N-Gain Type	Value	Category
Highest N-Gain	0.90	High
Lowest N-Gain	0.16	Low
Average N-Gain	0.61	Medium

Based on Table 9, it can be seen that the N-Gain results show that the highest value of 0.90 falls into the high category, indicating a very good improvement in conceptual understanding among some students, while the lowest value of 0.16 falls into the low category, indicating that there are still students with minimal improvement, and the average N-Gain of 0.61 falls into the moderate category, indicating that the implementation of the learning process was generally effective in improving students’ conceptual understanding.

Before testing the research hypothesis, a normality test was performed to determine whether the pretest and posttest data met the assumption of normality and to identify the appropriate statistical test for data analysis. The normality test was conducted using the One-Sample Kolmogorov–Smirnov test in SPSS version 27.0. Based on the normality test results, the appropriate hypothesis test was then selected to examine the difference between students’ pretest and posttest scores. The results of both the normality and hypothesis tests are presented in Table 10.

Table 10. Results of the Normality and Hypothesis Tests

Analysis	Test	Value	Interpretation
Normality (Pretest)	Kolmogorov–Smirnov Sig.	0.200	Normally Distributed
Normality (Posttest)	Kolmogorov–Smirnov Sig.	0.044	Not Normally Distributed
Hypothesis Test	Wilcoxon Signed-Rank Test (Z)	-4.860	Significant difference
Hypothesis Test	Asymp. Sig. (2-tailed)	0.001	$p<0.05$, H_0 rejected

Based on Table 10, The Kolmogorov–Smirnov normality test showed that the pretest scores were normally distributed ($p = 0.200$), whereas the posttest scores were not normally distributed ($p = 0.044$). Since one of the datasets did not satisfy the normality assumption ($p < 0.05$), the Wilcoxon Signed-Rank Test was used to analyze the difference between the pretest and posttest scores. The analysis yielded a test statistic of $Z = -4.860$ with an Asymp. Sig. (2-tailed) value of 0.001, which is below the significance level of 0.05. These findings indicate a statistically significant difference between students' conceptual understanding before and after the implementation of the learning intervention. The increase in posttest scores suggests that the implementation of the Inquiry-Based Learning model with a deep learning approach supported by Articulate Storyline contributed to improving students' conceptual understanding of fluid dynamics.

Discussion

The The improvement in students' conceptual understanding indicates that the implementation of the IBL model using a deep learning approach supported by Articulate Storyline can help students develop a deeper understanding of dynamic fluid concepts. This improvement occurs because students do not merely receive information from the teacher but are actively engaged in every stage of the inquiry process, from observing phenomena, formulating problems, developing hypotheses, collecting and analyzing data, to drawing conclusions. This process enables students to construct knowledge based on their own learning experiences, making the understanding they gain more meaningful (Siregar, 2024). Learning success is also supported by the deep learning approach, which promotes mindful, meaningful, and joyful learning, as well as the Articulate Storyline platform, which presents contextual phenomena, interactive simulations, and concept visualizations, thereby increasing student engagement throughout the learning process (Safitri et al., 2024; Dewi et al., 2025).

These findings are consistent with Mediana et al. (2025), who reported that the IBL model significantly improves students' conceptual understanding through active investigation and knowledge construction. However, the present study extends previous findings by integrating deep learning principles with Articulate Storyline, enabling students to engage in mindful, meaningful, and joyful learning supported by interactive digital media. This integration provides a richer learning experience that facilitates deeper conceptual understanding of fluid dynamics.

Improved conceptual understanding was also evident across all indicators, suggesting that the inquiry process was able to develop various aspects of students' conceptual understanding. Through observing phenomena, analyzing data, engaging in discussions, and drawing conclusions based on empirical evidence, students were able not only to interpret and classify concepts but also to provide examples, summarize information, compare relationships between variables, draw inferences, and explain concepts scientifically (Evagorou et al., 2015; Hadianto et al., 2023; Sriyani et al., 2023). The deep learning approach reinforces this process by encouraging students to connect concepts with real-world experiences and reflect on the results of their investigations (Wibowo et al., 2025; Prasetiya et al., 2025).

The substantial improvement in conceptual understanding is also closely related to the characteristics of fluid dynamics, which involve abstract concepts such as fluid flow, pressure, continuity, and Bernoulli’s principle. Through Articulate Storyline, these concepts were presented using interactive simulations and visualizations, allowing students to observe relationships between variables that are difficult to demonstrate directly in the classroom. Virtual investigations also reduced the abstract nature of these concepts by enabling students to manipulate variables, observe immediate outcomes, and connect theoretical principles with real-world phenomena. Consequently, students were able to construct more accurate and meaningful conceptual understanding.

The improvement was not only indicated by the magnitude of the N-Gain scores but was also influenced by students’ initial levels of conceptual understanding. The inferring indicator obtained the highest N-Gain score, followed by the comparing indicator. Both indicators had relatively low pretest scores, indicating that students’ initial abilities to draw inferences and make comparisons based on the available information were still limited. This condition provided greater room for improvement following the treatment, resulting in higher N-Gain scores. In contrast, the exemplifying, interpreting, and classifying indicators had relatively high pretest scores, indicating that most students had already developed a fairly good initial understanding of these indicators before the learning intervention. Consequently, the room for improvement was relatively limited, resulting in lower N-Gain scores than those of the other indicators. Meanwhile, the summarizing and explaining indicators had fairly good initial abilities, leaving room for improvement, although not as much as in the inferring and comparing indicators. These findings indicate that lower initial abilities provide greater room for improvement following the treatment, resulting in higher N-Gain scores than those of indicators for which students had already possessed relatively strong basic abilities.

Among all indicators, the abilities to draw inferences and make comparisons showed the greatest improvement because both abilities are developed through activities involving the analysis of relationships between variables and the drawing of conclusions based on investigation results (Erlina et al., 2017; Danial, 2017). Conversely, the exemplifying indicator showed the lowest improvement because it requires students to transfer concepts to new situations, which requires more diverse learning experiences. Overall, the improvement in students’ conceptual understanding across all indicators indicates that the implementation of the IBL model using a deep learning approach supported by Articulate Storyline was able to gradually enhance conceptual understanding. The systematic inquiry process, supported by interactive visualizations and mindful, meaningful, and joyful learning, enabled students to actively construct concepts based on their learning experiences.

CONCLUSION

The implementation of Inquiry-Based Learning (IBL) through a deep learning approach supported by Articulate Storyline improved students’ conceptual understanding of fluid dynamics. The improvement was reflected in the overall understanding of the concepts as well as across all conceptual understanding indicators, with the most notable gains found in the abilities to compare and draw inferences. These findings indicate that the integration of inquiry-based activities with mindful, meaningful, and joyful learning can help students construct a deeper understanding of abstract physics concepts. The use of Articulate Storyline also supported the learning process by providing interactive digital experiences that connected concepts with learning activities and phenomena. The findings demonstrate that the integration of IBL, deep learning, and interactive digital media can provide a student-centered learning experience that encourages active inquiry and meaningful knowledge construction. This approach can therefore be considered an instructional alternative for physics teachers in facilitating students' conceptual understanding, particularly when teaching abstract topics such as fluid dynamics. Furthermore, the findings provide a reference for designing physics learning that promotes active participation, meaningful learning, and sustained engagement.

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