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Integrating Inquiry-Based Learning and Cognitive Conflict Strategies to Enhance Critical Thinking in Undergraduate Physics Education

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Abstract: This research aimed to develop and evaluate an instructional device that integrates inquiry-based learning (IBL) with cognitive conflict strategies to enhance students' critical thinking skills in the topic of fluid mechanics. Employing the 4D development model—Define, Design, Develop, and Disseminate—the study involved 24 undergraduate students enrolled in a physics education program at Universitas Pendidikan Mandalika. The instructional device included syllabi, lesson plans, student worksheets (LKM), handbooks, and a critical thinking assessment instrument. Expert validation indicated high content and structural validity, with LKM and the assessment tool receiving the highest ratings (average score = 3.6). Classroom observations showed high implementation feasibility, particularly in the phases of cognitive conflict presentation and reflective discussion (average score = 3.6). Student learning outcomes were measured through pre- and post-tests, analyzed using Normalized Gain (N-Gain) and paired-sample t-tests. Results demonstrated a statistically significant improvement in critical thinking (average N-Gain = 0.58, $t = 25.82$, $p < 0.0001$). Student responses were overwhelmingly positive, and noted barriers such as initial confusion with the LKM format and time constraints were manageable. This study contributes a validated and adaptable model for fostering critical thinking through the synergistic application of inquiry learning and cognitive conflict, grounded in constructivist and conceptual change theory. The device holds promise for broader application across STEM disciplines in higher education.

Keywords: Inquiry-Based Learning; Cognitive Conflict; Critical Thinking; Physics Education; Instructional Design

INTRODUCTION

In the 21st century, critical thinking is recognized as a core competence necessary for individuals to navigate complex problems, make reasoned decisions, and engage in evidence-based analysis across various domains, including science and technology. Within science education, critical thinking plays a pivotal role in developing students' ability to interpret data, evaluate hypotheses, and draw logical conclusions. Recent research underscores the urgency of embedding critical thinking into educational processes, particularly in the teaching of physics, where abstract concepts often require deep conceptual understanding (Topsakal et al., 2022; Gusman et al., 2023).

Physics education, as part of STEM disciplines, offers a fertile ground for developing higher-order thinking skills through experimental, inquiry-oriented learning activities. However, in many educational contexts, particularly in Indonesia, physics instruction remains predominantly teacher-centered, focusing on rote memorization rather than concept mastery. Studies have indicated that such pedagogical practices hinder the development of students' critical thinking and problem-solving abilities (Cahyani et al., 2022; Tanjung et al., 2023). This mismatch between pedagogical approach and educational goals underscores the need for more student-centered learning strategies that actively engage learners in constructing knowledge through inquiry, reflection, and reasoning.

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Inquiry-based learning (IBL) has emerged as a highly effective model to address this issue. It encourages learners to engage in the scientific process—posing questions, forming hypotheses, collecting data, analyzing results, and drawing conclusions—thus fostering autonomy and deeper engagement with content. Multiple recent studies have affirmed the efficacy of IBL in physics education. For example, Nisa et al. (2023) found that students exposed to IBL outperformed those under traditional instruction in science process skills and conceptual understanding. Similarly, Wahyudi et al. (2019) and Yulkifli et al. (2020) reported that inquiry-based strategies significantly enhanced learners' critical thinking, scientific creativity, and positive attitudes toward science. These outcomes align with the broader educational objective of producing reflective, analytical, and adaptive learners.

The relevance of IBL has further expanded during the post-pandemic era, where digital adaptations such as simulation-based inquiry and online guided discovery have proven effective in remote learning environments. Prahani et al. (2023) demonstrated that virtual IBL models significantly improved students' conceptual understanding and critical thinking during emergency remote teaching, while Husnaini and Chen (2019) showed that technology-integrated inquiry facilitates active learning and performance in physics instruction. These findings suggest that IBL is not only pedagogically sound but also adaptable to varying instructional contexts.

While inquiry learning provides an environment conducive to developing critical thinking, its impact can be further strengthened through the integration of cognitive conflict strategies. Cognitive conflict occurs when students encounter new information that contradicts their existing understanding, prompting them to re-evaluate and reconstruct their mental models. This mechanism is particularly effective in science education, where misconceptions often obstruct conceptual change. Recent empirical studies confirm the transformative potential of cognitive conflict in physics instruction. Busyairi et al. (2022) found that introducing conceptual discrepancies during instruction improved students' understanding of force and motion. Verawati et al. (2019) highlighted that cognitive conflict enhances pre-service teachers' critical thinking and concept formation, while Mufit and Fitri (2022) showed improved comprehension of momentum through conflict-based teaching materials.

Moreover, Mufit et al. (2020) conducted a meta-analysis demonstrating the consistent positive impact of cognitive conflict strategies on science learning outcomes, supporting their adoption in educational practices. These findings validate cognitive conflict as an evidence-based pedagogical tool that challenges students' preconceived notions and supports deeper cognitive engagement, making it highly compatible with the constructivist paradigm that underpins modern science education.

From a theoretical standpoint, constructivist learning theory advocates that meaningful learning occurs when students actively build knowledge through experience and reflection. Within this framework, both inquiry and cognitive conflict serve as catalysts for learning, with inquiry promoting exploration and cognitive conflict triggering conceptual reorganization. Alarcón et al. (2023) argue that constructivist approaches foster environments where students connect new information with prior knowledge, engage collaboratively, and reflect critically. Complementing this, Cahyani et al. (2022) and Tanjung et al. (2023) emphasize that constructivist learning—particularly when enriched with problem-based learning (PBL)—enhances students' higher-order thinking skills, curiosity, and persistence in addressing complex scientific problems.

Furthermore, technological integration enhances constructivist strategies, offering flexible and personalized learning experiences. Yakar et al. (2020) demonstrated how mobile learning applications based on constructivist principles support learner autonomy and interactivity. Bouwma-Gearhart et al. (2019) further illustrated that immersing students in authentic scientific practices via constructivist methods boosts engagement and cognitive investment. These insights collectively emphasize the alignment between IBL, cognitive conflict, and constructivist learning in fostering critical thinking in physics education.

Recent theoretical developments have also proposed robust conceptual frameworks that integrate inquiry and cognitive conflict within broader educational systems. Ukwoma and Ngulube (2021) highlighted that well-structured conceptual frameworks are essential in guiding research design and interpreting complex educational interventions. Specifically, frameworks that synthesize IBL and cognitive conflict allow educators to scaffold student learning while providing opportunities for intellectual disequilibrium and resolution. As discussed by Jacobson et al. (2019), the interrelation between pedagogical components such as inquiry, conflict, and reflective dialogue is crucial in creating coherent educational systems. Schad et al. (2021) echoed this sentiment, calling for theoretical models that bridge educational technology and conceptual learning to support student-centered instruction in increasingly complex classroom environments.

In the Indonesian context, the integration of IBL and cognitive conflict has not been extensively explored, especially at the higher education level in science disciplines. While some studies have addressed each approach independently, there is a lack of research investigating their synergistic implementation in developing critical thinking among university students, particularly in physics topics such as fluid mechanics. Addressing this gap is essential, considering that critical thinking is a fundamental skill for future science professionals who must navigate uncertain, dynamic, and data-driven environments.

This study aims to develop and evaluate a learning device that integrates inquiry-based learning with cognitive conflict strategies to enhance critical thinking among physics education students, specifically in the topic of fluid mechanics. The novelty of this research lies in its integrative approach, which not only targets conceptual understanding but also fosters critical evaluation, inference-making, and scientific reasoning. Unlike previous studies that treat IBL and cognitive conflict in isolation, this study presents a cohesive instructional design grounded in constructivist theory, supported by empirical validation, and operationalized through tools such as syllabi, learning modules, and critical thinking assessments.

By implementing this integrated learning model at Physics Education program at Universitas Pendidikan Mandalika, the study provides insights into how inquiry and conflict-based approaches can be contextualized within Indonesian higher education. Furthermore, it offers a replicable pedagogical framework that can be extended to other scientific disciplines, thus contributing to broader efforts in improving science education quality in developing countries.

METHOD

Type of Research

This study applies a research and development (R&D) approach, aiming to design and validate an instructional device that integrates inquiry-based learning (IBL) with cognitive conflict strategies to enhance students' critical thinking skills in the domain of fluid mechanics. The development framework adopts the well-established 4D model by Thiagarajan et al. (1974), which consists of four systematic stages: Define, Design, Develop, and Disseminate. This model has been widely used in educational research for its structured approach to producing valid, practical, and effective learning resources tailored to specific content and learner needs. Figure 1 presents the summary of research procedure performed. The descriptions were also described in the next subsections of this paper.

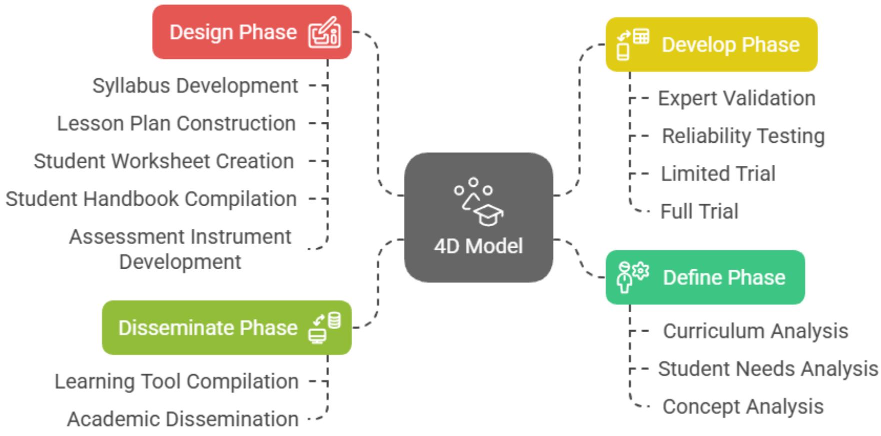

Figure 1. Overall research stages

The study involved 24 undergraduate students from the Physics Education program at Universitas Pendidikan Mandalika, who were enrolled in the "Fluid Mechanics" course. Participants were selected purposively based on course enrollment, and their demographic characteristics (age, gender, academic background) were recorded to contextualize the findings and enhance transferability (Xiang-feng & Yan-ping, 2023; Siahaan et al., 2023).

Research Procedure

The development procedure was structured into the following four stages of the 4D model:

Define Phase

This initial stage focused on identifying the core needs and problems in physics instruction related to critical thinking development. Activities included:

1. Curriculum analysis to align learning goals with national education standards;
2. Student needs analysis using diagnostic interviews and pre-existing performance data to uncover conceptual difficulties in fluid mechanics;
3. Concept analysis to map essential physics topics that commonly generate misconceptions and could serve as cognitive conflict triggers.

Design Phase

In this stage, the instructional design was conceptualized and constructed based on IBL principles and cognitive conflict theory. The design phase included:

1. Development of a syllabus aligned with inquiry-driven learning outcomes;
2. Construction of Lesson Plans (SAP) emphasizing stages such as hypothesis formulation, confrontation with anomalies, experimentation, and reflective discussion;
3. Creation of Student Worksheets (LKM) that embedded scenarios inducing cognitive conflict and guided students through inquiry steps;
4. Compilation of a Student Handbook (BAM) with supporting theory and cases;
5. Development of a Critical Thinking Assessment Instrument based on five core indicators: analysis, inference, decision making, evaluation, and conclusion drawing.

Develop Phase

This phase included expert validation and limited and full-scale trials:

1. Validation: Learning materials and instruments were evaluated by a panel of three experts in science education and instructional design. Validation data were collected using a standardized instrument and analyzed through the Content Validity Index

(CVI). Items with CVI ≥ 0.80 were considered acceptable (Yusfi et al., 2021; Pratami et al., 2023).

2. Reliability Testing: The critical thinking test underwent reliability analysis using Cronbach's alpha, with a threshold of $\alpha \geq 0.70$, confirming internal consistency (Tadros et al., 2023; Robertson & Evans, 2020).
3. Limited Trial: Conducted on a small group of students to evaluate practicality, implementation clarity, and to refine instructional flow.
4. Full Trial: Implemented with the complete sample of 24 students. Observations were conducted to assess instructional effectiveness and student engagement.

Disseminate Phase

In the final stage, revised learning tools were compiled for broader implementation. Results were documented for academic dissemination through institutional seminars, faculty resource development, and potential replication across other scientific disciplines.

Research Instruments

To comprehensively evaluate the effectiveness, practicality, and acceptance of the developed instructional device, five primary research instruments were utilized. These instruments were designed to align with the objectives of the study and to capture both quantitative and qualitative dimensions of student learning, instructional implementation, and material validity.

The validation sheet was employed to evaluate the content and construct validity of the instructional materials and assessment instruments. This sheet was completed by expert validators in the fields of physics education and instructional design. The instrument assessed several criteria, including the clarity of instructional content, logical structure, alignment with learning objectives, feasibility of implementation, and integration of inquiry and cognitive conflict strategies. Each item was rated using a four-point scale, and results were quantified using the Content Validity Index (CVI) to determine the degree of expert agreement. A CVI score ≥ 0.80 was considered acceptable, ensuring that the developed materials met content quality standards (Yusfi et al., 2021; Pratami et al., 2023). The use of expert judgment in this manner aligns with best practices in educational research, particularly for newly developed learning tools (Lee, 2022).

The observation sheet served to assess the fidelity of instructional implementation during classroom sessions. This instrument was completed by trained observers who monitored the learning process across several instructional stages, such as the presentation of cognitive conflict scenarios, student engagement in inquiry-based tasks, data analysis, and group reflections. Observers rated each component based on a standardized rubric to ensure consistency and objectivity. This tool provided insight into the quality of instruction delivery and the extent to which the learning environment supported critical thinking development (Olumorin et al., 2022). It also enabled the identification of potential deviations from the lesson plan, thus supporting process validation within the development framework.

The critical thinking test was the central instrument for measuring learning outcomes. It consisted of ten open-ended essay questions designed to assess five core indicators of critical thinking: analysis, inference, decision-making, evaluation, and conclusion. The items were developed based on existing critical thinking assessment models and adapted for physics contexts, particularly the topic of fluid mechanics. Responses were evaluated using a holistic scoring rubric that considered both cognitive depth and reasoning quality. This rubric was adapted from prior validated instruments and aligned with frameworks developed by Riegel and Crossetti (2019) and Julfianto et al. (2022), ensuring that it captured the multifaceted nature of critical thinking in science education. To establish reliability, the test was subjected to Cronbach's alpha analysis, with a minimum acceptable value of 0.70, reflecting internal consistency (Tadros et al., 2023; Robertson & Evans, 2020).

The student response questionnaire was designed to capture learners' perceptions and reactions to the instructional device. Administered after the learning intervention, the questionnaire employed a five-point Likert scale to measure various dimensions, including perceived clarity of the materials, engagement with inquiry tasks, usefulness of cognitive conflict activities, and the overall impact on students' critical thinking development. This instrument played a crucial role in assessing the acceptability and subjective effectiveness of the learning model from the students' perspective. Data from the questionnaire were analyzed descriptively to identify patterns of satisfaction and areas for improvement, reflecting the importance of learner feedback in instructional evaluation (Arruti & Paños-Castro, 2023).

Lastly, the learning barrier log sheet provided a qualitative tool for capturing the challenges and obstacles students faced during the implementation of the instructional device. This instrument was completed by both students and observers, who recorded difficulties related to instructional clarity, time constraints, understanding of experimental procedures, and engagement with reflective tasks. These qualitative insights were then analyzed thematically to identify recurring barriers and to inform iterative revisions of the learning model. The use of such tools to explore learning constraints has been shown to enhance the practicality of instructional innovations and support inclusive, responsive teaching practices (Carter et al., 2022; Díaz-Olavarrieta et al., 2023).

Data Analysis

A comprehensive data analysis procedure was implemented to assess the validity, effectiveness, and practicality of the developed instructional device. The approach combined quantitative and qualitative techniques to ensure triangulation of findings and to provide a robust evaluation of each research component. The analyses addressed instrument validity, instructional feasibility, student learning gains, perceptions, and contextual learning barriers.

Validation analysis was conducted by calculating the average scores from expert judgments using the Content Validity Index (CVI) framework. Each instructional component—syllabus, lesson plan (SAP), student worksheet (LKM), student handbook (BAM), and critical thinking test—was rated on a four-point Likert scale. Items with a mean score ≥3.0 were considered valid, aligning with established thresholds for educational material validation (Yusfi et al., 2021; Pratami et al., 2023). This process ensured content relevance, clarity, and structural integrity, which are critical for instructional effectiveness. The validation process also incorporated qualitative comments from experts to guide the refinement of materials, in accordance with recommendations from Lee (2022) and Kusumayanti and Bayu (2021), who emphasized the importance of expert-based iterative evaluation in instructional development.

To evaluate the implementation feasibility, observational data were analyzed by averaging scores recorded by trained observers during the instructional sessions. These scores assessed various stages of implementation, such as presentation of conflict scenarios, inquiry engagement, experimentation, and reflective discussion. Implementation fidelity was categorized using a four-point scale with interpretive benchmarks: very good (>3.6), good (2.8–3.6), poor (1.9–2.7), and very poor (<1.9). This approach provided structured insights into how well the instructional model functioned in practice and allowed for adjustments based on real-time feedback (Olumorin et al., 2022).

Student learning improvements in critical thinking were evaluated using a combination of descriptive and inferential statistics. The primary method used to measure individual learning gains was the Normalized Gain (N-Gain), calculated from students' pre-test and post-test scores on the critical thinking test. N-Gain values were categorized as high (>0.7), moderate (0.3–0.7), and low (<0.3), following Hake's (1998) established guidelines. To verify whether observed gains were statistically significant, a paired-sample t-test was performed using SPSS software, with a significance level set at $p < 0.05$. This combination of gain-based and inferential analysis aligns with best practices in educational research for measuring learning effect size and statistical significance (Siahaan et al., 2023; Amo-Asante & Bonyah, 2023).

The analysis of the student response questionnaire employed a descriptive statistical approach. Students' Likert-scale responses were converted into percentage values and categorized based on strength of agreement: very strong (81–100%), strong (61–80%), moderate (41–60%), weak (21–40%), and very weak (0–20%). This analysis provided insight into student engagement, perceived instructional quality, and satisfaction with the learning experience. The use of descriptive categories facilitated pattern identification and guided interpretation, especially in aligning learner perceptions with observed outcomes (Arruti & Paños-Castro, 2023; Ismail et al., 2023).

Finally, the identification of learning barriers was based on direct notes and observations recorded by both participants and classroom observers during the instructional process. These notes provided descriptive accounts of difficulties encountered in real time, without employing formal qualitative coding procedures. The issues reported commonly included limited familiarity with the inquiry format, challenges in formulating hypotheses, time management during experimentation, and initial confusion when confronted with cognitive conflict scenarios. Although not analyzed through thematic coding, these recorded observations served as valuable input for evaluating the practical aspects of the instructional implementation. By directly documenting obstacles in the field, this approach facilitated targeted revisions to improve instructional clarity, pacing, and support mechanisms. Such descriptive documentation is essential in development-oriented research, as it ensures the responsiveness of instructional models to student needs and classroom dynamics (Carter et al., 2022; Díaz-Olavarrieta et al., 2023).

RESULTS AND DISCUSSION

Validation of Instructional Devices

The validation process is a critical step in the development of instructional materials, ensuring that each component is pedagogically sound, content-relevant, and practically applicable. In this study, expert validation was conducted for five instructional components: the syllabus, Lesson Plan (SAP), Student Worksheets (LKM), Student Handbook (BAM), and Critical Thinking Test. The validation involved three subject-matter experts in physics education and instructional design, who assessed each component based on four primary dimensions: content relevance, structural clarity, pedagogical coherence, and alignment with inquiry-based and cognitive conflict strategies.

Table 1. Average Expert Validation Scores

Instructional Component	Average Score	Category
Syllabus	3.46	Good
Lesson Plan (SAP)	3.5	Good
Student Worksheets (LKM)	3.6	Very Good
Student Handbook (BAM)	3.5	Good
Critical Thinking Test	3.6	Very Good

Each expert completed a standardized validation sheet using a four-point Likert scale ranging from "1 = Not Valid" to "4 = Very Valid." The results of this process, presented in Table 1, show that all components received average scores above 3.0, meeting the acceptance threshold for content validity (Yusfi et al., 2021; Pratami et al., 2023). The Student Worksheet (LKM) and the Critical Thinking Test received the highest average scores (3.6), categorized as "Very Good." These two components were particularly effective in embedding the core instructional strategies—IBL and cognitive conflict—into student learning tasks.

The syllabus, with an average score of 3.46, was deemed to clearly articulate the course competencies and learning indicators, aligned with inquiry-oriented outcomes. However, feedback from validators indicated the need for more explicit integration of inquiry steps within the syllabus structure to further guide educators in aligning lesson objectives with student-centered pedagogies.

The Lesson Plan (SAP) received an average score of 3.5, indicating solid structural integrity and coherence in sequencing. Validators highlighted the effective incorporation of inquiry phases—questioning, experimentation, and reflection—and the presence of built-in conflict scenarios. However, they recommended enhancing the clarity of assessment criteria to better capture students' critical thinking progress throughout instructional sessions.

The Student Handbook (BAM) also scored 3.5, reflecting good quality. It was praised for its conceptual explanations and contextual examples. However, experts suggested improving the visual layout and adding illustrations, especially to support abstract concepts like fluid dynamics, to improve accessibility for visual learners. This suggestion is consistent with recent studies that emphasize multimodal design in science learning materials to improve cognitive engagement (Ertikanto et al., 2023).

The Critical Thinking Test, scoring 3.6, was recognized as a well-structured assessment tool. The items assessed five core cognitive domains: analysis, inference, evaluation, decision-making, and drawing conclusions. Each item was crafted to stimulate higher-order thinking through real-world physics problems involving fluid mechanics. Experts validated the test's alignment with the learning objectives and its capacity to elicit varied levels of reasoning, a crucial criterion in critical thinking assessment (Julfianto et al., 2022; Riegel & Crossetti, 2019). Furthermore, the test underwent internal consistency analysis via Cronbach's alpha, producing a reliability coefficient above 0.70, indicating acceptable reliability (Tadros et al., 2023).

This validation phase not only confirmed the technical and pedagogical quality of the instructional devices but also guided necessary revisions. Suggestions such as enhancing the instructional flow in SAP and incorporating visual supports in BAM were implemented prior to the limited and full-scale trials. Such iterative refinement reflects best practices in instructional development, wherein continuous expert feedback ensures alignment with theoretical models and learner needs (Lee, 2022; Kusumayanti & Bayu, 2021).

Moreover, the results underscore the importance of combining content expertise with design principles in validating educational interventions. The inclusion of inquiry and cognitive conflict as dual anchors in the learning process required validators to assess not just content fidelity but also cognitive scaffolding and learner engagement potential. This duality is supported by constructivist instructional theory, which posits that learners achieve conceptual change when faced with dissonance and are provided with tools and guidance to resolve it (Alarcón et al., 2023).

Implementation Feasibility

The implementation feasibility of the developed instructional device was evaluated through direct classroom observation, focusing on how effectively the components were enacted during the learning process and how well students engaged with the inquiry and cognitive conflict-based strategies. This evaluation provided essential insights into the practicality of the device in real instructional settings, particularly within the context of teaching fluid mechanics in higher education.

Data were collected using a structured observation sheet filled out by trained observers during the learning sessions. Observers assessed student activities and instructional flow across seven key phases: introduction, cognitive conflict presentation, identification of variables and hypotheses, experimentation, data analysis, discussion and conclusion, and reflection. Each phase was scored on a four-point Likert scale, with interpretive categories: Very Good (>3.6), Good (2.8–3.6), Poor (1.9–2.7), and Very Poor (<1.9).

The results, summarized in Table 2, show that the average implementation score across all phases was 3.5, which falls into the "Good" category. Notably, the Cognitive Conflict Presentation and Discussion and Conclusion phases achieved the highest scores (3.6), categorized as "Very Good." These findings suggest that the instructional strategies designed to create cognitive disequilibrium—such as presenting contradictory phenomena or unexpected experimental outcomes—were effective in stimulating student engagement and promoting critical discussion.

Table 2. Instructional Implementation Observations

Learning Phase	Average Score	Category
Introduction	3.5	Good
Cognitive Conflict Presentation	3.6	Very Good
Variable Identification & Hypothesis Formulation	3.4	Good
Experimentation	3.5	Good
Data Analysis	3.4	Good
Discussion & Conclusion	3.6	Very Good
Reflection	3.5	Good
Overall Average	**3.5**	**Good**

These results align with prior studies emphasizing that structured inquiry learning, when supported with clear instructional scaffolds such as worksheets and conflict scenarios, can foster deeper engagement and support higher-order cognitive processes (Wahyudi et al., 2019; Syukri et al., 2023). The slightly lower scores in phases such as Variable Identification and Data Analysis suggest that these components may require additional scaffolding or time allocation, especially for students less familiar with self-directed inquiry.

Field notes from observers and instructors indicated that students initially faced challenges adjusting to the LKM format, particularly in framing testable hypotheses and documenting observations. These difficulties are consistent with findings from Budiastra et al. (2019), who reported that transitioning from passive to active learning structures often requires adaptation time, especially in traditionally teacher-centered environments. To mitigate these issues, facilitators provided additional guidance in the early sessions, after which students demonstrated increased autonomy and engagement.

Moreover, the experimentation and reflection phases benefited from the integration of hands-on tasks and guided questions, which helped students connect theoretical concepts to observed phenomena. This hands-on engagement is strongly supported in the literature as a key factor in the development of scientific reasoning and critical thinking in physics education (Nisa et al., 2023; Alarcón et al., 2023).

The feasibility of the instructional device was further evidenced by its smooth integration into existing classroom schedules, without requiring substantial deviation from institutional guidelines or infrastructure. This adaptability is crucial for promoting the wider adoption of innovative learning models, particularly in institutions with varying levels of instructional resources (Tshering & Yangden, 2021).

Importantly, the effective implementation of the Cognitive Conflict Presentation phase aligns with the theoretical framework of conceptual change. By introducing discrepant events or experimental outcomes that challenge students' preconceptions, the instruction creates a state of cognitive dissonance. Students are then guided through resolution via experimentation and discussion, a process central to conceptual reconstruction as described in constructivist models of learning (Schad et al., 2021; Verawati & Hikmawati, 2021).

Improvement in Critical Thinking Skills

One of the primary objectives of this study was to evaluate whether the integration of inquiry-based learning (IBL) and cognitive conflict strategies could effectively improve students' critical thinking skills in the context of fluid mechanics. To measure this, students were administered a Critical Thinking Test before and after the intervention. The test assessed five core indicators: analysis, inference, decision-making, evaluation, and drawing conclusions, which are considered essential components of higher-order cognitive processes (Julfianto et al., 2022; Riegel & Crossetti, 2019).

The quantitative data demonstrated a statistically significant improvement in student performance. As shown in Table 3, the average pre-test score was substantially lower than the post-test score, with the calculated Normalized Gain (N-Gain) reaching a mean of 0.58, which falls into the "moderate" improvement category. This suggests that the learning intervention had a meaningful and measurable effect on students' ability to think critically about physics concepts.

Table 3. Summary of Pre-Test and Post-Test Scores and N-Gain

Test	Variabel	W	t-statistic	p-value	Decision
Normality (Shapiro–Wilk)	Pre-Test	0.9460	–	0.2214	Normal
Normality (Shapiro–Wilk)	Post-Test	0.9379	–	0.1462	Normal
Normality (Shapiro–Wilk)	N-Gain	0.9831	–	0.9448	Normal
Paired t-test	Post-Test vs Pre-Test	–	25.8209	0.0000	Significant

(*See full detailed dataset in Appendix Table A1*)

In addition to descriptive analysis, inferential statistical techniques were employed to confirm the robustness of the findings. Normality testing using the Shapiro–Wilk test indicated that the distribution of pre-test, post-test, and N-Gain data met the assumptions for parametric analysis ($p > 0.05$). Consequently, a paired-sample t-test was conducted to determine whether the improvement in scores was statistically significant. The results showed a t-value of 25.82 with a p-value < 0.0001, indicating a highly significant difference between pre-test and post-test performance. This finding corroborates the effectiveness of the instructional device and confirms that the intervention positively influenced students' critical thinking development.

The use of a paired-sample t-test in this context follows methodological standards in education research, particularly for pre-post designs. Studies across various disciplines have similarly applied t-tests to validate the impact of instructional interventions on learning outcomes (Liana, 2023; Wahab et al., 2023). This method not only demonstrates statistical significance but also supports internal validity by accounting for within-subject variations.

While statistical significance confirms that an effect exists, it is also essential to consider the practical significance of the results. The moderate effect size (based on the N-Gain) reflects a substantial educational benefit, aligning with literature that emphasizes the importance of interpreting both p-values and effect sizes in education studies (Štemberger, 2021; Park & Suh, 2021). In this case, the observed gains are not only statistically meaningful but also pedagogically impactful, suggesting that students became more adept at processing, evaluating, and synthesizing complex information in a structured scientific context.

Further reinforcing these findings are students' qualitative responses, which revealed increased confidence in applying critical thinking during inquiry tasks. Many students reported that the cognitive conflict scenarios prompted them to reconsider initial assumptions, engage in deeper reflection, and participate more actively in experimental discussions. These responses are consistent with theories of conceptual change, which argue that learners must experience cognitive disequilibrium before reconstructing their understanding (Verawati & Hikmawati, 2021; Alarcón et al., 2023).

Moreover, the improvement in critical thinking observed in this study aligns with recent research demonstrating the efficacy of IBL enhanced by cognitive conflict strategies. For instance, Sulistyani et al. (2022) found that combining guided inquiry with conflict-based learning significantly elevated students' science process skills and critical reasoning. Similarly, Agustina & Mufit (2023) reported that cognitive conflict led to more durable conceptual understanding and reflective thinking habits, particularly in complex physics domains.

The distribution of N-Gain scores among students also highlights the inclusive effectiveness of the instructional model. Although most students fell into the "moderate" gain category, one student achieved a "high" gain (0.73), and none showed regression. This consistency across the cohort supports the adaptability and scalability of the device in supporting diverse learners. It also speaks to the structured nature of the instructional design, which provided sufficient scaffolding while allowing room for individual cognitive development.

Student Responses and Learning Barriers

Assessing students' responses to instructional interventions provides valuable insight into the acceptability, engagement, and perceived usefulness of the learning model. In this study, students' perceptions were gathered using a post-intervention response questionnaire, which captured their reflections on the clarity, relevance, and impact of the instructional components—particularly the integration of inquiry-based learning (IBL) and cognitive conflict strategies.

The findings revealed that approximately 90% of participants expressed positive responses toward the instructional approach. Students indicated that the learning process was more engaging compared to conventional lectures and allowed them to actively explore, test, and refine their understanding of fluid mechanics concepts such as buoyancy, fluid pressure, and flow dynamics. This aligns with studies showing that inquiry learning, when implemented effectively, can enhance both student motivation and conceptual mastery (Nisa et al., 2023; Wahyudi et al., 2019).

Specifically, students appreciated the inclusion of cognitive conflict scenarios, which were embedded within the Lembar Kegiatan Mahasiswa (LKM). These scenarios presented unexpected or contradictory outcomes that challenged students' prior assumptions. As several students reported, such moments "forced us to think more critically and reflect on why our initial ideas were wrong," demonstrating the capacity of the strategy to induce cognitive disequilibrium—a central mechanism in constructivist learning (Verawati et al., 2019; Agustina & Mufit, 2023). The reflective discussions following these conflicts helped students consolidate new understanding, reinforcing the transformative power of metacognitive engagement in scientific reasoning (Alarcón et al., 2023).

In addition to the structured questionnaire, insights were gathered from participant and observer notes during classroom sessions to identify practical challenges or barriers faced during implementation. Although the data were not analyzed through formal qualitative coding procedures, the descriptive records yielded several recurring themes that were crucial for evaluating the device's practical feasibility.

The most frequently noted challenges included initial confusion with the LKM format, especially in formulating hypotheses and documenting observations in a structured way. This was particularly evident in the early sessions, where students exhibited dependency on instructor guidance. Observers reported that many students were not accustomed to open-ended tasks requiring independent analysis—a common limitation in transitioning from teacher-centered to student-centered instruction (Budiastra et al., 2019). However, as the sessions progressed, students gradually developed confidence and autonomy, indicating that the learning device provided sufficient scaffolding for adaptation.

Another barrier noted was time management during experimentation, especially when students attempted to complete complex inquiry tasks within limited session durations. Some students expressed the need for additional time to engage more deeply with the material, particularly in interpreting experimental results and participating in reflective discussions. This issue has also been identified in prior studies on IBL, where time constraints often hinder the depth of conceptual exploration (Tshering & Yangden, 2021; Aristeidou et al., 2020). This highlights the need for flexible scheduling or integration of asynchronous components in future implementations.

A few logistical issues were also observed, including limited familiarity with laboratory equipment and inconsistent pacing among student groups. These challenges, although minor, indicate the importance of preparatory briefings and differentiated facilitation strategies when implementing inquiry-based tasks, especially those involving experimentation.

Despite these barriers, no students expressed negative overall impressions of the learning experience. In fact, many suggested that the inquiry-conflict model be applied to other physics topics and praised its ability to make abstract concepts more relatable and memorable. This high level of acceptance suggests that the instructional device was not only theoretically robust but also well-received in practice.

The combination of strong positive responses and manageable implementation barriers reflects a balance between pedagogical innovation and classroom realism. It also confirms that the developed instructional model is both scalable and adaptable, making it suitable for broader application in higher education science curricula.

Pedagogical and Theoretical Implications

The findings of this study provide robust empirical and theoretical support for the integration of inquiry-based learning (IBL) and cognitive conflict strategies in the development of critical thinking skills in higher education, particularly in physics instruction. The discussion below synthesizes these findings with current literature, offering insight into both pedagogical effectiveness and theoretical alignment with constructivist learning models.

The validation results (see Table 1) demonstrate that all instructional components met the criteria for content validity, with Student Worksheets (LKM) and the Critical Thinking Test achieving the highest expert ratings (3.6, categorized as "Very Good"). These components were central to the delivery of cognitive conflict and inquiry, indicating that the instructional model was structurally sound and pedagogically coherent. Expert suggestions for layout improvements and visual enhancements reflect the importance of accessibility and user-friendliness in instructional material design (Pratami et al., 2023; Ertikanto et al., 2023).

From an implementation standpoint, the observations (Table 2) confirmed that the device could be successfully enacted in classroom settings. With an average implementation score of 3.5 across learning phases, and the cognitive conflict and discussion stages reaching 3.6 ("Very Good"), the data underscore that students were highly engaged when confronted with discrepant events that challenged their prior understanding. This aligns with research showing that cognitive disequilibrium triggers reflective thinking and motivates learners to seek conceptual clarity (Verawati & Hikmawati, 2021; Alarcón et al., 2023).

The most significant contribution of this study is the demonstrated improvement in students' critical thinking skills (Table 3). With an average N-Gain of 0.58, categorized as "moderate," and a t-value of 25.82 ($p < 0.0001$) in the paired-sample t-test, the data confirm that students developed stronger reasoning, evaluation, and problem-solving capabilities through the intervention. The statistical significance of these findings, combined with positive student responses (90% favorable), reinforces the instructional model's effectiveness, both in practice and in learning outcomes. This supports the conclusion that inquiry learning—when enhanced by cognitive conflict—does not merely engage students, but also leads to measurable cognitive gains (Wahab et al., 2023; Sulistyani et al., 2022).

Theoretically, the results align closely with the constructivist paradigm, which holds that meaningful learning occurs when students actively construct knowledge through experience, experimentation, and reflection. The cognitive conflict strategy, which introduces anomalies to provoke conceptual revision, is a direct application of conceptual change theory. The student responses and improvement trends suggest that the learning model created optimal conditions for this process—i.e., exposure to disequilibrium, followed by guided inquiry and reflection, leading to restructured understanding (Schad et al., 2021; Eggen & Kauchak, 2012).

Furthermore, the study responds to calls in the literature for instructional models that simultaneously support scientific content mastery and higher-order cognitive development. While traditional physics instruction often prioritizes content delivery over cognitive engagement, the IBL-conflict approach reverses this dynamic by placing students at the center of the learning process. The LKM, in particular, functioned not merely as a worksheet but as a thinking scaffold, guiding students through hypothesis formulation, testing, and revision—skills at the core of scientific literacy (Julfianto et al., 2022; Ubaidillah et al., 2023).

The findings also have practical pedagogical implications. Given that students initially experienced difficulties with self-directed inquiry and time constraints during experimentation, there is a need to incorporate more flexible instructional scheduling and perhaps pre-instructional orientation to the inquiry model. These observations, while not formal barriers to implementation, point to important logistical and affective considerations for scaling the model across diverse classrooms (Budiastra et al., 2019; Tshering & Yangden, 2021).

Finally, the positive outcomes observed here suggest the model is transferable to other STEM disciplines, especially those that involve conceptual complexity and require students to challenge intuitive misconceptions (e.g., chemistry, biology, and environmental science). The scaffolding inherent in the instructional materials—especially the combination of LKM and conflict scenarios—can be easily adapted for different scientific domains.

The pedagogical implications of this study highlight the strength of combining inquiry-based learning with cognitive conflict to promote active, reflective, and critical engagement with scientific content. The theoretical contributions underscore the value of cognitive disequilibrium as a trigger for deeper learning, firmly situating this model within constructivist and conceptual change frameworks. The evidence from Tables 1–3 collectively affirms that the developed instructional device is not only valid and practical, but also transformative in supporting the development of critical thinking skills in higher education.

CONCLUSION

This study concludes that the integration of inquiry-based learning (IBL) with cognitive conflict strategies constitutes an effective instructional model for enhancing critical thinking skills in undergraduate physics education, particularly in the domain of fluid mechanics. The developed instructional device—comprising syllabi, lesson plans, student worksheets, handbooks, and critical thinking assessments—was validated by subject-matter experts and demonstrated both pedagogical coherence and structural integrity. Implementation observations confirmed the model's practicality in classroom settings, with students showing strong engagement and adaptability throughout the inquiry phases. Quantitative results revealed a statistically significant improvement in students' critical thinking, as evidenced by an average N-Gain of 0.58 and a highly significant paired-sample t-test result ($p < 0.0001$). These findings align with constructivist and conceptual change theories, which posit that meaningful learning is driven by active engagement and the resolution of cognitive disequilibrium. Student feedback further supported the model's relevance and impact, emphasizing its potential to deepen conceptual understanding and promote metacognitive reflection. Overall, the study offers a validated, scalable framework for advancing critical thinking in science education through a strategic combination of inquiry and conflict-based pedagogy.

RECOMMENDATION

Based on the study's findings, it is recommended that higher education institutions, particularly in the sciences, adopt instructional models that integrate inquiry-based learning with cognitive conflict strategies to foster higher-order thinking skills among students. Educators should be trained in facilitating inquiry processes and designing cognitive conflict scenarios that challenge students' misconceptions and promote conceptual reorganization. To improve implementation fidelity, preparatory sessions that introduce students to the inquiry format and critical thinking expectations should be incorporated into course design. Future research is encouraged to replicate and adapt this instructional model in other STEM disciplines such as chemistry, biology, and environmental science to evaluate its cross-disciplinary applicability. Additionally, longitudinal studies should be conducted to assess the long-term impact of this approach on students' academic performance and cognitive development. Given the success of this model in the context of fluid mechanics, there is also potential for developing subject-specific variations—for example, cognitive conflict-driven LKM for optics, thermodynamics, or electricity—tailored to the conceptual challenges inherent in each topic. These efforts will contribute meaningfully to the broader goal of cultivating analytical, adaptive, and reflective learners in science education.

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Appendix

Table A1

Initial	Pre-Test		Criteria	Post-Test		Criteria	N-Gain	Category
	Score	Value		Score	Value			
A1	23	57.5	Less Critical	32	80	Critical	0.53	Moderate
A2	21	52.5	Less Critical	34	85	Very Critical	0.68	Moderate
A3	20	50	Less Critical	33	82.5	Very Critical	0.65	Moderate
A4	22	55	Less Critical	33	82.5	Very Critical	0.61	Moderate
A5	16	40	Very Less Critical	31	77.5	Critical	0.63	Moderate
A6	18	45	Less Critical	31	77.5	Critical	0.59	Moderate
A7	16	40	Very Less Critical	28	70	Critical	0.50	Moderate
A8	11	27.5	Very Less Critical	29	72.5	Critical	0.62	Moderate
A9	17	42.5	Very Less Critical	28	70	Critical	0.48	Moderate
A10	18	45	Less Critical	32	80	Critical	0.64	Moderate
A11	18	45	Less Critical	30	75	Critical	0.55	Moderate
A12	14	35	Very Less Critical	33	82.5	Very Critical	0.73	High
A13	19	47.5	Less Critical	33	82.5	Very Critical	0.67	Moderate
A14	17	42.5	Very Less Critical	31	77.5	Critical	0.61	Moderate
A15	19	47.5	Less Critical	30	75	Critical	0.52	Moderate
A16	14	35	Very Less Critical	32	80	Critical	0.69	Moderate
A17	19	47.5	Less Critical	32	80	Critical	0.62	Moderate
A18	19	47.5	Less Critical	30	75	Critical	0.52	Moderate
A19	18	45	Less Critical	31	77.5	Critical	0.59	Moderate
A20	17	42.5	Very Less Critical	29	72.5	Critical	0.52	Moderate
A21	17	42.5	Very Less Critical	32	80	Critical	0.65	Moderate
A22	18	45	Less Critical	28	70	Critical	0.45	Moderate
A23	19	47.5	Less Critical	31	77.5	Critical	0.57	Moderate
A24	19	47.5	Less Critical	31	77.5	Critical	0.57	Moderate