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Critical Thinking in Fluid Dynamics Learning: A Systematic Review of Learning Models

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Abstract: This study aims to identify learning models implemented to promote student's critical thinking skills in fluid dynamics learning and synthesize evidence regarding their reported effectiveness. Using the PRISMA framework, seven empirical studies published between 2021 and 2025 and focusing on senior high school students were selected according to predefined inclusion criteria. The review examined student's initial critical thinking conditions, instructional approaches, and reported learning outcomes. The findings indicate that student's initial critical thinking skills in fluid dynamics were generally low to moderate, suggesting persistent difficulties in higher-order thinking processes. The reviewed studies implemented five instructional approaches, namely Problem-Based Learning, Guided Inquiry, RADEC, Metacognition Based Discovery Learning, and Think Pair Share, all of which were reported to support student's critical thinking development. Several studies employing pretest–posttest measures reported moderate to high learning gains, while posttest-based studies showed higher critical thinking performance among students receiving innovative instruction. The reviewed evidence also suggests that students often experience difficulties in relating relationships among pressure, velocity, and flow rate to mathematical representations and scientific reasoning. Overall, student-centered instructional approaches contribute positively to critical thinking development in fluid dynamics learning, although their effectiveness varies across learning contexts and assessment indicators.

Keywords: Critical thinking; Fluid dynamics; Learning models

Introduction

Critical thinking is a fundamental cognitive ability in physics learning because physics requires the ability to analyze phenomena, examine the relationships among variables and derive conclusions supported by empirical evidence (Demircioglu et al., 2023; García-Carmona, 2025). Without critical thinking skills, students often emphasize memorizing formulas rather than developing an understanding of their physical meaning and the conceptual relationships behind them (Bao & Koenig, 2019). As part of physics education research, critical thinking plays a role in helping students solve non-routine problems, test scientific arguments, and interpret experimental data logically (Gormally et al., 2012).

Critical thinking skills are essential competencies that need to be developed because through these skills, students can assess information objectively, examine the consistency of reasoning, and understand physics concepts more deeply and meaningfully (Batdı et al., 2024; Pols et al., 2021). According to Facione (1990), critical thinking comprises interpretation, analysis, evaluation, inference, explanation, and self-regulation, which are fundamental cognitive processes in scientific reasoning. These processes enable students to evaluate evidence, justify conclusions, and make reasoned judgments when solving scientific problems (Frisilla & Hardeli, 2022; Kresin et al., 2024; Wan, 2023). The

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importance of critical thinking in physics education is not only related to academic achievement but also to preparing students to face the challenges of the digital age and the demands of 21st-century learning (Mutiara et al., 2024; Santos-Meneses & Drugova, 2023; Taufik et al., 2025). With well-developed critical thinking skills, students are better able to analyze problems in depth, evaluate alternative explanations, and construct logical solutions based on available evidence (Demircioglu et al., 2023; Dias-Oliveira et al., 2024; Putri et al., 2023; Zulyusri et al., 2023), particularly in learning contexts involving everyday phenomena such as fluid dynamics.

Fluid dynamics is a fundamental topic in physics education because it is closely related to many real-world phenomena, such as blood flow, piping systems, and air movement (Liu, 2021; Sijs et al., 2023). Despite its relevance to everyday life, fluid dynamics has a high level of conceptual complexity (Cossu et al., 2024). Concepts such as flow velocity, pressure variation, flow rate, the continuity equation, and Bernoulli's principle require students to integrate mathematical reasoning with physical interpretation (Schäfle & Kautz, 2021). In addition, these concepts are associated with the work theorem and the conservation of mechanical energy (Serway & Jewett, 2014). Many fluid dynamics concepts are also abstract and difficult to visualize, particularly pressure distribution and flow patterns (Rasmi et al., 2025). Consequently, students need strong critical thinking skills to analyze relationships among variables, evaluate the validity of assumptions underlying fluid models, and explain fluid phenomena in various contexts (Khabibah & Sukarmin, 2025; Slominski et al., 2023; Suarez et al., 2017). Hence, critical thinking is an essential skill for understanding fluid dynamics, as students must continuously evaluate evidence, analyze variable relationships, and construct logical explanations for fluid phenomena.

In fact, previous studies still show that student's critical thinking skills in fluid dynamics remain low (Affandy et al., 2019; Hulwa et al., 2024). Students often experience difficulties in analyzing the relationships among pressure, velocity, and cross-sectional area, leading to misconceptions in understanding Bernoulli's principle and the continuity equation (Bessas et al., 2024). This condition is evident when students assume that faster-moving fluids always exert greater pressure or accept explanations that are inconsistent with established fluid laws without critically evaluating the underlying evidence and reasoning (Koto & Ilhami, 2023). Such responses indicate limitations in essential aspects of critical thinking, including the ability to analyze causal relationships among variables, evaluate the validity of scientific arguments, and draw conclusions based on physical principles rather than intuitive beliefs (Ahzari & Akmam, 2025; Demircioglu et al., 2023). As a result, students frequently struggle to apply fluid dynamics concepts in unfamiliar situations (Affandy et al., 2019; Kaye & Ogle, 2022), solve problems requiring evidence-based reasoning, and explain fluid phenomena scientifically and coherently (Goszewski et al., 2013; Ramadhani et al., 2022). These difficulties are often reinforced by instructional approaches that emphasize procedural problem solving and formula application while providing limited opportunities for students to justify their reasoning, analyze relationships among variables, and construct evidence-based explanations (Dwyer & Walsh, 2020). Consequently, students tend to rely on intuitive beliefs rather than critically evaluating whether their explanations are consistent with scientific evidence and physical principles when interpreting fluid phenomena (Arfia & Handican, 2024). Such conceptual misunderstandings and uncritical reliance on intuitive reasoning constitute significant barriers to the development of critical thinking in fluid dynamics.

Evidence from previous studies indicates that student's critical thinking skills in fluid dynamics remain insufficient and require further development (Paillusson & Booth, 2025). To address this issue, recent research has explored a range of student-centered learning models within fluid dynamics instruction (Wahdah et al., 2023). This tendency is consistent with constructivist learning theory, which suggests that knowledge is actively constructed through learners' engagement in inquiry, problem solving, discussion, and reflection (Bruner, 1961; Vygotsky, 1980). Such learning experiences are considered conducive to the development of higher-order thinking skills, including critical thinking. Among the approaches reported in the literature are Problem-Based Learning (PBL), Guided Inquiry, RADEC (Read, Answer, Discuss, Explain, Create), Metacognition Based Discovery Learning, and Think Pair Share (TPS) (Hulwa et al., 2024; Ilema et al., 2024; Ramanda et al., 2024; Selviyana et al., 2022; Septian et al., 2025; Suparinda & Wasis, 2022; Zahro et al., 2025). These learning models engage students in activities that require them to analyze information, evaluate evidence, construct explanations, and reflect on their reasoning processes (Anggraeni et al., 2023; Morris, 2025). Despite their shared objective of fostering critical thinking, the findings reported across studies vary in terms of implementation and learning outcomes. However, evidence regarding the effectiveness of these approaches remains dispersed across individual studies and has not yet been synthesized within a dedicated review. Consequently, it remains unclear which learning models have been most frequently implemented in fluid dynamics learning and how they contribute to the development of student's critical thinking skills. A systematic review is therefore necessary to bring together the available evidence and provide a clearer picture of current research trends and reported learning outcomes in this area. Therefore, this systematic literature review aims to examine and synthesize studies published between 2021 and 2025 to identify learning models employed in fluid dynamics instruction and analyze their potential contributions to student's critical thinking skills.

Several systematic literature reviews have examined critical thinking skills in physics and science education from different perspectives, including studies that mapped critical thinking across various physics topics (Hikmah et al., 2023; Tugirin et al., 2025), reviews of assessment instruments used to measure critical thinking skills (Barid et al., 2025), and analyses of instructional approaches designed to foster critical thinking in science learning (Fatimah, 2022). While these reviews have contributed valuable insights into the development and assessment of critical thinking skills, they have not specifically focused on fluid dynamics learning. Fluid dynamics is a topic that requires students to coordinate multiple interrelated concepts, such as pressure, velocity, flow rate, and cross-sectional area, while applying scientific reasoning to explain observable phenomena (Suarez et al., 2017). Given these distinctive conceptual challenges, a review focusing specifically on fluid dynamics is needed to provide a more topic specific understanding of how learning models have been implemented to promote student's critical thinking skills.

Method

This study employed a Systematic Literature Review (SLR) to systematically identify, evaluate, and synthesize empirical studies investigating learning models aimed at improving student's critical thinking skills in fluid dynamics. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which consists of four stages: identification, screening, eligibility, and inclusion (Moher et al., 2009). The reporting procedure was adapted from Banda et al. (2021).

The literature search was conducted using academic databases and journal platforms, including Google Scholar, ERIC, Scopus, SpringerLink, and Taylor & Francis Online. These sources were selected to ensure comprehensive coverage of relevant studies and to minimize publication bias. The search was limited to articles published between 2021 and 2025 to capture recent developments in physics education research. Boolean operators were employed to combine keywords related to the research topic. The primary search string used was ("critical thinking" OR "critical thinking skills") AND ("fluid dynamics" OR "fluid flow") AND ("learning model" OR "learning approach" OR "instructional model"). Additional keyword combinations were applied when necessary to identify studies relevant to the research objectives.

Prior to the screening process, inclusion and exclusion criteria were established to ensure the relevance and quality of the selected studies. Studies were included if they: (1) focused on fluid dynamics learning in physics education; (2) involved students as research participants; (3) examined critical thinking skills as a primary or secondary research outcome; (4) implemented a learning model, instructional approach, or learning strategy; (5) reported empirical research findings; (6) were published in peer-reviewed journals between 2021 and 2025; and (7) for Indonesian publications, were published in journals accredited by the Science and Technology Index (SINTA). Studies were excluded if they: (1) did not focus on fluid dynamics topics; (2) did not assess critical thinking skills; (3) only developed instructional materials or learning media without implementation and evaluation; (4) involved participants other than students; (5) were review articles, conference abstracts, editorials, or opinion papers; or (6) lacked sufficient methodological information.

The study selection process followed the PRISMA framework. During the identification stage, a total of 4,962 records were retrieved from the selected sources, consisting of 1,997 records from Google Scholar, 600 from ERIC, 200 from Scopus, 1,911 from Taylor & Francis Online, and 254 from SpringerLink. All records were imported into Microsoft Excel for data management, and duplicate records were identified and removed using the "Remove Duplicates" feature. This process resulted in the removal of 31 duplicate records, leaving 4,931 unique records for further screening.

During the screening stage, titles and keywords were reviewed according to the predefined inclusion and exclusion criteria. A total of 4,713 records were excluded because they were not relevant to fluid dynamics, critical thinking skills, or learning models, leaving 218 records for abstract screening. The abstracts of these records were subsequently examined to determine their relevance to the research questions. During this stage, 196 records were excluded because their objectives, participants, variables, or research contexts did not align with the scope of the review. Consequently, 22 full-text articles were retained for eligibility assessment.

In the eligibility stage, the full texts of the remaining articles were examined independently by the researchers to ensure consistency in the selection process. Fifteen studies were excluded because they focused solely on instructional material development without implementation, did not report critical thinking outcomes, involved non-student participants, or failed to satisfy the established eligibility criteria. Ultimately, seven studies met all inclusion criteria and were included in the final review and synthesis. Although international databases and journal platforms were searched extensively, no international journal articles met all eligibility criteria. Therefore, all studies included in the final synthesis originated from Indonesian journals accredited by SINTA, consisting of one article published in a SINTA 2 journal, three articles published in SINTA 3 journals, and three articles published in SINTA 4 journals. The detailed article selection process is presented in Figure 1, while the results of each PRISMA stage are summarized in Table 1.

The selected studies were analyzed using descriptive qualitative synthesis. Information extracted from each article included publication year, educational level, research design, learning model or instructional approach, instruments used to assess critical thinking skills, and the main findings related to critical thinking improvement in fluid dynamics learning. The extracted data were subsequently categorized, compared, and synthesized to identify research trends and determine which learning models have been reported as effective in enhancing student's critical thinking skills in fluid dynamics.

This review addressed two research questions: (1) What learning models or instructional approaches have been implemented to promote student's critical thinking skills in fluid dynamics learning during the period 2021–2025?; (2) Which learning models or instructional approaches have been reported as effective in improving student's critical thinking skills in fluid dynamics?

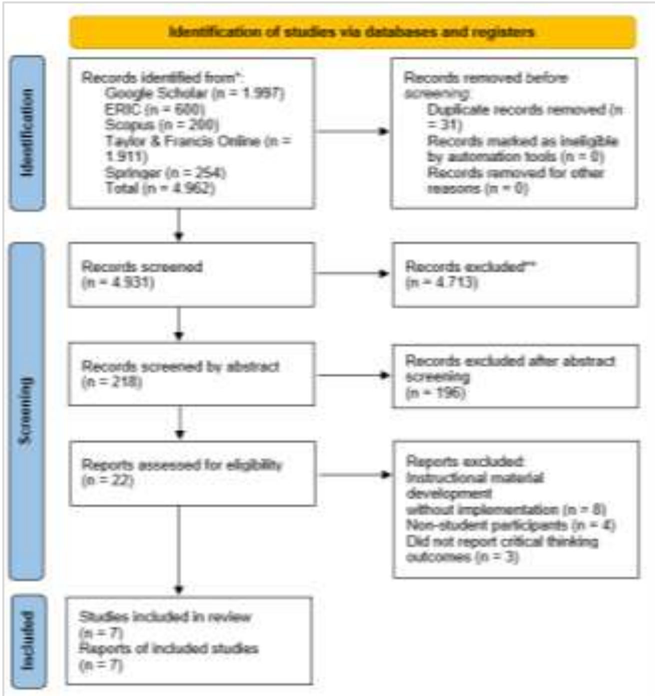

Figure 1. PRISMA flow diagram of the study selection process

Table 1. PRISMA Screening Results

Prisma Phase	Description	n
Identification	Records identified through database and platform searching	4.962
Identification	Duplicate records removed	31
Screening	Records screened by title and keywords	4.931
Screening	Records excluded after title screening	4.713
Screening	Records screened by abstract	218
Screening	Records excluded after abstract screening	196
Eligibility	Full-text articles assessed for eligibility	22
Eligibility	Full-text articles excluded	15
Included	Studies included in the final review	7

Result and Discussion

The reviewed articles were published between 2021 and 2025 in reputable journals and were all conducted at the senior high school level. In fluid dynamics material, critical thinking skills are highly important because students are faced with abstract concepts, complex flow phenomena, and problems involving many variables (Khabibah & Sukarmin, 2025). Therefore, studies on learning strategies oriented towards the enhancement of critical thinking skills are increasingly relevant to support meaningful and contextual physics learning in the 21st century.

The study of student's critical thinking skills in fluid dynamics material was conducted by summarizing the findings from seven research articles that met all inclusion criteria. An overview of student's levels of critical thinking skills is shown in Table 2.

Referring to Table 2, the reviewed studies generally indicate that student's critical thinking skills in fluid dynamics were at low to moderate levels. This finding aligns with studies by Febriani et al. (2025) and Nurjanah et al. (2022), which reported that student's critical thinking abilities in fluid dynamics learning tended to remain low. Such conditions suggest that many students have not yet developed sufficient capacity to analyze relationships among fluid variables, critically evaluate flow-related phenomena, or construct arguments based on scientific evidence and fundamental physics principles.

Table 2. Initial Conditions of Student's Critical Thinking Skills

Author	Initial Condition of Critical Thinking Skills
(Selviyana et al., 2022)	Initial critical thinking skills were generally categorized as low to moderate prior to the intervention
(Suparinda et al., 2022)	The average pretest score (14.6) indicated very low critical thinking skills before guided inquiry instruction
(Septian et al., 2025)	Pretest results showed that student's critical thinking skills were predominantly in the low category
(Zahro et al., 2025)	Initial assessments indicated low to moderate critical thinking levels in both experimental and control groups
(Ramanda et al., 2024)	The study employed a posttest-only design; therefore, student's initial critical thinking levels were not explicitly measured
(Ilema et al., 2024)	Pretest results indicated that student's critical thinking skills were generally low before implementation of the TPS model
(Hulwa et al., 2024)	Students in the experimental and control groups demonstrated relatively comparable critical thinking skills prior to the intervention

Although the reviewed studies consistently reported limitations in student's critical thinking skills, direct comparisons among specific critical thinking indicators should be interpreted cautiously because different studies employed different assessment frameworks and instruments. Some studies highlighted difficulties in analysis and evaluation, whereas others reported weaknesses in inference, clarification, or other higher-order thinking components. Therefore, variations across indicators are more likely attributable to differences in measurement approaches than to contradictory findings.

These findings indicate that traditional instructional approaches have not optimally supported the development of critical thinking skills in fluid dynamics learning. Consistent with the findings of Prayogi et al. (2024), instructional practices that rely heavily on memorization and provide limited opportunities for investigation, reasoning, and evidence-based discussion are insufficient to meet current educational demands emphasizing critical thinking and problem-solving abilities. Therefore, learning models and instructional strategies that promote inquiry, problem-solving, conceptual reasoning, and active cognitive engagement are needed to improve student's critical thinking skills in fluid dynamics learning (Lestari, 2026; L. Lu et al., 2025).

Accordingly, the analysis of the seven studies included in the final review focuses on exploring the development of student's critical thinking skills through the application of instructional models in physics education, with particular emphasis on fluid dynamics learning. A comprehensive summary of the analyzed studies, including the learning models employed, research designs, and principal findings, is presented in Table 3.

Based on Table 3, all reviewed studies investigated the impact of innovative instructional models on student's critical thinking skills in fluid dynamics through quasi experimental research designs. Although the studies employed different student-centered instructional approaches, they shared a common emphasis on active student engagement and higher-order thinking processes. This pattern is consistent with broader evidence in science education indicating that learning environments which encourage inquiry, collaboration, and self-regulated learning tend to support the development of critical thinking skills (Fauziah et al., 2026). Similarly, Xhomara (2022) reported that student centered instruction provides more opportunities for reasoning, problem solving, and evidence based discussion than traditional teacher-centered approaches, thereby contributing to stronger critical thinking performance.

Although the reviewed studies employed different instructional models and research designs, a common pattern emerged across the findings: students exposed to student-centered learning environments generally demonstrated better critical thinking performance than those experiencing conventional instruction. However, direct comparisons among studies should be approached cautiously because the effectiveness of each intervention was measured using different research designs, instruments, and analytical procedures. In studies adopting pretest–posttest designs, effectiveness was reflected through improvements in student's scores over time, whereas posttest-only studies evaluated effectiveness through differences between experimental and control groups (Khusniyah et al., 2026; Z. Lu et al., 2025). Despite these methodological differences, the overall evidence points to the positive contribution of active and inquiry-oriented learning experiences in supporting critical thinking development within fluid dynamics learning.

The review identified five instructional approaches used to promote critical thinking in fluid dynamics learning between 2021 and 2025, namely Problem-Based Learning, Guided Inquiry, RADEC, Metacognition-Based Discovery Learning, and Think–Pair–Share. Guided Inquiry was the most frequently reported approach, appearing in three studies, while the remaining models were represented by one study each. Most studies employed quasi experimental designs and assessed critical thinking using essay tests or structured multiple-choice instruments. These findings indicate that recent research has predominantly focused on student-centered instructional approaches emphasizing inquiry, reasoning, collaboration, and reflective thinking.

Table 3. Summary of Learning Models, Research Designs, and Main Findings in the Reviewed Studies

Author	Learning Model	Design & Instruments	Results
(Selviyana et al., 2022)	Problem-Based Learning (PBL)	Quasi-experimental design; critical thinking essay test consisting of five questions	Students taught using PBL demonstrated higher critical thinking performance than those in the control group
(Suparinda & Wasis, 2022)	Guided Inquiry	Quasi-experimental design; six essay questions assessing critical thinking skills	Guided inquiry significantly improved student's critical thinking skills in fluid dynamics learning
(Septian et al., 2025)	RADEC (Read, Answer, Discuss, Explain, Create)	Quasi-experimental non-equivalent control group design; 18 multiple-choice questions assessing critical thinking skills	The RADEC model improved student's critical thinking skills, producing a moderate N-Gain (0.60) and a very high effect size (2.45), indicating positive learning outcomes measured through different effectiveness indicators
(Zahro et al., 2025)	Metacognition-Based Discovery Learning	Nonequivalent control group design; seven multiple-choice questions assessing clarification, basic support, inference, advanced clarification, and strategic thinking	The model effectively improved student's critical thinking skills and cognitive achievement in fluid dynamics learning
(Ramanda et al., 2024)	Guided Inquiry Assisted by PhET Simulations	Posttest-Only Control Group Design	Students receiving guided inquiry assisted by PhET simulations achieved significantly higher posttest critical thinking scores than those receiving conventional instruction
(Ilema et al., 2024)	Think–Pair–Share (TPS)	Pretest–posttest control group design	Students in the experimental group demonstrated higher critical thinking performance than those in the control group
(Hulwa et al., 2024)	Guided Inquiry	Nonequivalent control group design	Guided inquiry contributed significantly to the improvement of student's critical thinking skills in physics learning

Problem-Based Learning (PBL)

From the seven studies reviewed, one investigation explicitly implemented the Problem-Based Learning (PBL) approach in teaching fluid dynamics. The findings indicated that PBL effectively enhanced student's critical thinking performance. Students in the experimental group demonstrated higher levels of critical thinking than those in the control group, and no students remained in the low critical thinking category after the intervention.

A notable aspect of the PBL study is its emphasis on contextual problem solving as the starting point of learning. Rather than receiving information directly from the teacher, students were required to identify relevant variables, evaluate available information, and justify proposed solutions. Such learning demands are particularly relevant to fluid dynamics because understanding fluid behavior involves reasoning about interconnected quantities such as pressure, velocity, flow rate, and cross-sectional area. Students must not only apply equations but also explain why changes in one variable influence the others. Under these circumstances, PBL appears to provide a meaningful context for students to practice analytical and evaluative thinking while constructing conceptual understanding.

This finding is consistent with Pangaribuan et al. (2025), who reported that PBL contributes positively to the development of student's critical thinking skills through active engagement in problem identification, information exploration, and collaborative solution construction. These characteristics are particularly important in fluid dynamics because students must coordinate multiple interrelated variables simultaneously when explaining fluid behavior. Furthermore, the use of authentic problems as learning stimuli encourages students to select relevant information, assess alternative strategies, and make decisions based on evidence, which are essential elements of critical thinking (Hmelo-Silver, 2004).

Guided Inquiry

Among the instructional approaches identified, guided inquiry emerged as the most frequently implemented model, appearing in three of the seven reviewed studies. The findings consistently indicate positive effects on student's critical thinking skills. In studies employing pretest–posttest designs, students demonstrated significant improvements following instruction, whereas studies using posttest-only designs reported significantly higher critical thinking performance among students receiving guided inquiry instruction compared with those experiencing conventional learning.

The prominence of guided inquiry among the reviewed studies is not surprising given the conceptual characteristics of fluid dynamics. Many fluid phenomena cannot be observed directly, and students often rely on intuitive explanations that conflict with scientific principles (Kamilah et al., 2025). For example, some students assume that faster-moving fluids always exert greater pressure, despite predictions derived from Bernoulli's principle. Guided inquiry addresses this challenge by placing students in situations where they must formulate questions, examine evidence, and evaluate the consistency of their explanations.

The integration of PhET simulations further strengthens this process by allowing students to visualize relationships among pressure, velocity, and flow patterns that are otherwise difficult to observe in classroom settings (Mashami et al., 2023). Viewed collectively, the reviewed studies suggest that guided inquiry supports critical thinking not merely because students become more active, but because they are repeatedly required to justify claims using evidence and scientific reasoning. Consistent with these findings, Arifin et al. (2025) reported that inquiry-oriented learning approaches play a substantial role in strengthening student's critical thinking skills through structured investigative activities.

RADEC Learning Model

One study included in this review implemented the RADEC (Read, Answer, Discuss, Explain, Create) learning model in fluid dynamics instruction. The findings demonstrated that the RADEC model contributed positively to the improvement of student's critical thinking skills. Students who participated in RADEC-based learning showed better critical thinking performance following the instructional intervention, indicating that the model provides meaningful opportunities for engaging in higher-order thinking processes.

The effectiveness of RADEC in fluid dynamics learning may be associated with the characteristics of the topic, which requires students to connect conceptual understanding with mathematical reasoning (Septian et al., 2025). Through reading activities, students develop an initial understanding of concepts such as fluid continuity and Bernoulli's principle (Dewi et al., 2019). The answering and discussion stages encourage students to examine relationships among pressure, velocity, and flow rate, while the explanation and creation stages require them to justify ideas and apply concepts to new situations. These learning experiences support the development of critical thinking skills while helping students build a deeper understanding of fluid dynamics concepts. Evidence from previous studies also supports the potential of RADEC to foster higher-order thinking skills. Komara et al. (2025) reported that students who learned through RADEC demonstrated stronger analytical and reflective thinking than those taught using conventional approaches. Likewise, Lami et al. (2026) found that RADEC-based instruction improved student's ability to evaluate information and communicate scientific reasoning. Taken together, these studies reinforce the view that RADEC can provide meaningful learning experiences that support the development of critical thinking in science education.

Metacognition Based Discovery Learning

Research applying metacognition based discovery learning demonstrates that integrating metacognitive strategies into discovery learning exerts a significant positive impact on student's critical thinking skills and cognitive achievement. The experimental group obtained higher N-Gain and effect size scores than the control group and exhibited a positive relationship between cognitive achievement and critical thinking skills.

The findings from this study highlight an aspect that is often overlooked in physics instruction, namely student's awareness of their own thinking processes. In fluid dynamics, students frequently encounter situations in which an initial intuition appears reasonable but does not align with scientific explanations. Under such conditions, merely discovering concepts may not be sufficient. Students also need opportunities to monitor their reasoning, identify inconsistencies, and reconsider conclusions when confronted with new evidence.

The positive relationship observed between cognitive achievement and critical thinking skills suggests that metacognitive regulation may help students engage more deeply with conceptual and quantitative aspects of fluid topics (Pamungkas et al., 2019). This interpretation is consistent with Dessie et al. (2024), who emphasized that self-regulated and reflective learning environments support the development of higher-order thinking skills, including critical thinking.

The Think Pair Share (TPS) Cooperative Model

One study included in this review implemented the Think Pair Share cooperative learning model in teaching fluid dynamics concepts. The findings indicated that students in the experimental group demonstrated greater gains in critical thinking skills than those in the control group, thereby supporting the effectiveness of structured peer interaction and idea exchange in fostering student's argumentation and reflective thinking (Ilema et al., 2024).

The effectiveness of the Think–Pair–Share model appears to stem from the opportunity it provides for students to externalize and evaluate their reasoning (Huang et al., 2023). In fluid dynamics learning, students are often required to interpret diagrams, explain causal relationships among variables, and justify conclusions using physical principles (Gustina et al., 2025). Individual reasoning may not always reveal weaknesses in understanding; however, discussion with peers can expose alternative viewpoints and prompt students to reconsider their assumptions.

Through this process, argumentation becomes part of learning rather than merely a means of reporting answers. Collaborative reasoning enables students to compare explanations of relationships among pressure, velocity, and flow rate while evaluating alternative interpretations of fluid phenomena. The reviewed findings therefore suggest that structured dialogue can serve as an important mechanism for strengthening critical thinking and conceptual understanding in physics classrooms. Similar observations were reported by Mudana et al. (2023), who highlighted the role of cooperative learning in promoting meaningful discussion and critical reflection.

Overall, the reviewed studies consistently indicate that student centered instructional approaches contribute positively to the development of student's critical thinking skills in fluid dynamics learning. Although the instructional models differed in their learning procedures, they shared common characteristics, including active student participation, opportunities for inquiry and problem solving, collaborative discussion, conceptual reasoning, and reflective thinking. These learning experiences encourage students to analyze relationships among fluid variables, evaluate evidence, justify conclusions, and construct scientifically grounded explanations. Taken together, the reviewed evidence indicates that multiple instructional approaches have been reported as effective in improving student's critical thinking skills in fluid dynamics learning.

Conclusion

This systematic literature review identified five instructional approaches used to promote student's critical thinking skills in fluid dynamics learning during 2021–2025, namely Problem Based Learning, Guided Inquiry, RADEC, Metacognition Based Discovery Learning, and Think Pair Share, with Guided Inquiry being the most frequently implemented approach. Across the reviewed studies, these learning models were reported to improve student's critical thinking skills and generally resulted in better outcomes than conventional instruction. The findings indicate that learning activities involving inquiry, problem solving, discussion, and reflection provide opportunities for students to reason about relationships among fluid variables and develop evidence based explanations of fluid phenomena. Nevertheless, several studies reported that higher order aspects of critical thinking remained challenging for many students. These difficulties appear to be related to persistent misconceptions about pressure, velocity, and flow rate, as well as challenges in connecting conceptual understanding with mathematical reasoning. Future research should further investigate the contribution of different instructional approaches to the development of critical thinking skills in fluid dynamics learning. More standardized assessment frameworks may also help strengthen comparisons across studies.

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Author Contributions

Conceptualization, methodology, C.T.H. and P.; validation, formal analysis, P., A.T, and C.T.H.; investigation, resources, C.T.H. and M.A.; writing—original draft preparation, writing—review and editing C.T.H.; visualization, supervision, P., A.T., and M.A.; project administration, funding acquisition, P. and C.T.H.

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Conflicts of Interest
The authors declare no conflict of interest.

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