Jurnal Ilmiah Pendidikan Fisika
https://ppjp.ulm.ac.id/jurnal/index.php/jipf/index
e-ISSN : 2549-9963 p-ISSN: 2549-9955
Vol 10 No 1 2026
DOI: https://doi.org/10.20527/jipf.v10i1.17398

Guided Inquiry and Multirepresentation Integration in a Dynamic Fluids Module for Strengthening Critical Thinking

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Article Info

Article history:
Received: November 24, 2025
Accepted: March 17, 2026
Published: March 24, 2026

Keywords:
Critical thinking
Fluid dynamics
Guided inquiry
Merdeka curriculum
Multirepresentation

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Abstract

Students' critical thinking skills in dynamic, fluid materials are still considered low because the learning process generally takes place conventionally and is limited to verbal and mathematical presentations. This causes students to have difficulty understanding abstract concepts, analyzing phenomena, and drawing logical conclusions. This research aims to develop a guided inquiry and multirepresentation-based dynamic fluid teaching module as an innovative effort to strengthen critical thinking skills. The research results show that: (1) The teaching module is valid because the validation results for the lesson plan (3.40), teaching materials (3.40), student worksheets (3.40), and critical thinking test (3.63) meet the valid category; (2) The module is practical because the learning implementation score is 3.57, which is in the good category; and (3) The teaching module is effective because the N-gain scores for critical thinking and learning outcomes are 0.69 each, which is in the moderate category. Multirepresentation enables students to understand concepts through various forms of representation, allowing them to grasp ideas more effectively, while guided inquiry provides structured stages of scientific investigation that enrich the learning experience. The integration of these two strategies into a single teaching package becomes the main contribution of this research, as it has been shown to make physics learning more meaningful and simultaneously foster higher-order thinking skills. This finding indicates that teachers can utilize the module to strengthen contextual learning in line with the Merdeka Curriculum, as well as use it as a reference for developing innovative teaching materials for other abstract physics topics or by incorporating digital technology.

To cite this article: Milisa, M., Mahtari, S., & Suyidno, S. (2026). Guided inquiry and multirepresentation integration in a dynamic fluids module for strengthening critical thinking. *Jurnal Ilmiah Pendidikan Fisika, 10*(1), 87-100.

INTRODUCTION

Education plays a crucial role in developing human resources (HR) who are obedient to God, behave well, are healthy, knowledgeable, skilled, innovative, independent, and become democratic and responsible members of society. Education not only aims to increase a person's intelligence but also to build good character and personality. In this context, the learning process becomes the main element for optimizing the development of students' potential, both intellectually, socially, and emotionally. In line with the needs of the 21st century, students are expected to master learning and innovation skills that include critical thinking, problem-solving, communication, collaboration, creativity, and

innovation (Nikmah, 2023). This ability is an essential asset for students, especially at the high school level, to keep pace with the rapidly advancing science and technology (Apriyani, 2020; Meilani & Aiman, 2020; Ridha, 2022).

Although the hope is visible, the reality on the ground still shows differences. Initial research findings on 11th-grade students at State Senior High School 1, Banjarmasin, indicate that their critical thinking abilities are very low, with an average score of 0.42. The majority of students (88.59%) were only able to achieve the interpretation indicator, while 11.41% were able to meet both the interpretation and prediction indicators. Furthermore, no student was able to meet the analysis indicators or the conclusion results. This situation confirms that the teaching strategies used so far have not been successful in developing deep and structured critical thinking skills. Abstract physics instruction, such as in the topic of fluid dynamics, when delivered solely verbally and mathematically, often causes students difficulty in understanding concepts, analyzing problems, and solving problems comprehensively (Arini & Juliadi., 2018).

To address this gap, learning innovations are required that not only deepen conceptual understanding but also regularly cultivate critical thinking skills in dynamic fluids. One proposed solution is the development of a structured, guided inquiry–based module integrated with multirepresentation. In this approach, each phase of guided inquiry is aligned with specific critical thinking indicators: exploration and problem formulation foster interpretation, data collection and analysis develop analytical skills, and hypothesis formulation as well as conclusion drawing promote inference and evaluation. The integration of verbal, graphical, and mathematical representations further strengthens these processes by requiring students to examine meaning, assess consistency across representations, and construct evidence-based justifications. Through this structured integration, dynamic fluids are positioned not merely as conceptual content but as an epistemic context intentionally designed to develop and reinforce students' critical thinking in solving contextual problems.

Several previous studies have demonstrated that the multirepresentation method is effective in enhancing students' conceptual understanding and higher-order cognitive abilities (Maharani et al., 2015; Mardatila et al., 2019). In addition, the multirepresentation-based discovery and inquiry learning models have also been proven to strengthen students' conceptual mastery, analytical skills, and critical thinking abilities (Chrestella, 2021; Fitriana, 2020; Sariningrum et al., 2017; Talib & Amiroh, 2022). Critical thinking (CT) is an important goal in physics education. However, improving students' CT in specific contexts, such as fluid dynamics, remains a challenge. Learning in this subject matter often focuses on procedural problem solving, such as using the continuity principle and Bernoulli's equation, rather than training students to interpret, analyze, evaluate, conclude, and justify their reasoning. Inquiry and multirepresentation approaches have been proven to improve conceptual understanding and higher-order thinking skills in general, but they are rarely designed explicitly and systematically to foster well-defined indicators of CT in the context of fluid dynamics. Therefore, a learning design that deliberately integrates multi-representation and guided inquiry is needed, not only to improve conceptual mastery but also to develop and evaluate specific aspects of critical thinking. Thus, this is a study that aims to improve students' critical thinking skills through the development of an inquiry module based on multirepresentation and focusing on fluid dynamics. Therefore, this research offers an innovation in the development of a dynamic fluid teaching module that not only presents material through various forms of representation, such as verbal, mathematical, and visual, but is also combined with structured, guided inquiry stages. This approach is designed so that learners do not just receive information, but actively discover and construct concepts independently through a scientific process that encourages analysis,

evaluation, and conclusion. Thus, the integration of multirepresentation and guided inquiry into a single learning device is expected to be an innovative strategy that is applicable, relevant to the characteristics of 21st-century physics learning, and aligned with the spirit of the Merdeka Curriculum, which emphasizes the development of critical thinking skills and meaningful learning.

Based on this explanation, critical thinking ability is a crucial competency that needs to be developed in physics learning, particularly in the context of dynamic fluid materials. Therefore, this research aims to produce a dynamic fluids teaching module using multirepresentation-based guided inquiry to enhance students' critical thinking skills.

METHODS

This research uses a one-group pretest and posttest design. This design was chosen because it is suitable for testing the effectiveness of a guided inquiry-based and multi-representation-based dynamic fluid teaching module on improving students' critical thinking skills. In this design, before being given treatment in the form of teaching modules, students are first administered a pretest to assess their critical thinking skills. After that, students participate in learning using the developed teaching modules. At the end of the treatment, they are given the identical Posttest to measure the improvement in learning outcomes and critical thinking skills. The product trial design used in this study can be seen in Table 1.

Table 1 Product trial design

Pretest	Dependent Variable	Posttest
O_1	X	O_2

Explanation:

O_1 = Pretest of critical thinking skills

X = Treatment (learning with dynamic fluid teaching modules using guided inquiry and multirepresentation-based)

O_2 = Posttest of critical thinking skills

This research was conducted at SMA Negeri 1 Banjarmasin during the first semester of the 2024/2025 academic year, involving 38 students from class XI-A as subjects. The research design used is a one-group pretest and posttest design, where learning is conducted face-to-face over three meetings. The research activity began with a pretest to assess the students' initial abilities, followed by a learning process that utilized teaching modules based on guided inquiry and multirepresentation at each meeting, and concluded with a posttest. The pretest and posttest data were analyzed to determine the effectiveness of the module in improving students' critical thinking skills.

The developed module is implemented through structured guided inquiry stages, namely problem orientation, exploration and hypothesis formulation, data collection and analysis, verification and discussion, and conclusions and reflection. In the orientation stage, students are exposed to contextual fluid dynamic phenomena supported by simple visual, verbal, and graphic representations to train their interpretation skills in identifying information and interpreting physical situations. The exploration and hypothesis research stage encourages students to formulate hypotheses about relationships between variables with the help of symbolic and mathematical representations, thereby developing inference skills. Next, in the data collection and analysis stage, students conduct experiments or simulation analyses and present the results in the form of tables, graphs, and equations, with an emphasis on translation between representations to practice skills and examine consistency of meaning. In the verification and discussion stage, students compare findings with theoretical concepts and obtain evidence and hypotheses to develop evaluation skills.

Finally, through conclusions and reflection, students formulate logical and data-based generalizations with clear justification. Multiple representations (verbal, graphic, and mathematical) are systematically integrated in each stage to study the coordination of meaning and argumentation based on evidence so that the intervention mechanisms become clear, mapped to specific critical thinking indicators, and allow for replication by other researchers and teachers.

The validity of the teaching module is assessed based on the average score of the validator's assessment obtained from the teaching material assessment instrument, with the module validation aspect criteria categorized as very good, good, quite good, less good, or not good. The module is considered valid if it receives a minimum category of good (Widoyoko, 2016). Additionally, the teaching modules were tested to determine their level of consistency. The consistency level of the modules was calculated based on the percentage of agreement among the three validators. The assessment instrument for the teaching module will be reliable if the percentage agreement value is $\geq 75\%$ (Borich, 1994).

The practicality of the teaching module was analyzed based on the feasibility of learning, which was calculated by comparing the obtained score with the maximum score. The results of this calculation were used to evaluate the effectiveness of integrating the teaching module into the learning process. The feasibility criteria for the teaching module are determined by referring to categories adapted from (Widoyoko, 2016).

The effectiveness of the module was analyzed using an integrated test instrument designed to measure two aspects simultaneously, namely students' mastery of dynamic fluid concepts and critical thinking skills. This instrument took the form of four essay questions compiled in the context of dynamic fluids, covering the principles of continuity, Bernoulli's equation, and their application in real-life situations. Each question not only assesses conceptual accuracy but also includes indicators of critical thinking, namely interpretation, analysis, inference, evaluation, and conclusion drawing, so that the measurement of learning outcomes and critical thinking skills is carried out in an integrated manner in a single test. The effectiveness of learning is analyzed based on Learning Outcome Test (LOT) data using gain score or normalized gain (g) calculations. This formula is obtained from the difference between the posttest and pretest scores, compared to the maximum score minus the pretest value. The results of the subsequent calculations are categorized according to the criteria (Hake, 1999).

The achievement of critical thinking skills was analyzed based on the scores for each indicator on the pretest and posttest. These scores were obtained by adding up the points earned by students according to the assessment rubric. The development of students' critical thinking skills was analyzed through learning test results, specifically the pretest and posttest scores for each aspect of critical thinking skills evaluated. The data obtained were then calculated using the percentage formula, which is the ratio of the number of points earned to the maximum number of points, then multiplied by 100. The resulting values were then averaged for each aspect of critical thinking skills and adjusted to the assessment categories. The critical thinking skills categories refer to the value intervals presented by Ermayanti (2016).

RESULTS AND DISCUSSION

The development of a dynamic fluid teaching module, based on multiple representations, aims to enhance students' critical thinking skills. As an effort to support learning sustainability, this module is designed for 11th-grade students at SMA Negeri 1 Banjarmasin. The module is developed based on the independent curriculum to align it with the school's needs. The module content includes general information, key components, and

supporting attachments. The cover section contains the material title, grade level, author's name, university logo, and the Merdeka Belajar logo, as well as illustrations related to the topic of dynamic fluids. The module was created using Microsoft Word and Canva. The following is the cover of the fluid dynamics teaching module using guided inquiry based on multi-representation, which can be seen in Figure 1.

Figure 1 Module cover

The dynamic fluid teaching module created by the researcher is designed to strengthen students' critical thinking skills in each sub-chapter or session. In terms of interpretation, students are presented with a phenomenon at the beginning of the subchapter. They are asked to pose various scientific questions related to it, thereby motivating them to enhance their interpretation skills. Next, in the prediction aspect, by using the syntax of the guided inquiry model, which involves formulating hypotheses, students are guided to construct hypotheses or tentative answers to the questions they have created, contributing to their prediction skills. In terms of analysis, upon entering the data collection stage, students are provided with observation data and asked to answer questions through literature studies, utilizing modules, books, videos, and journal articles, and applying multirepresentational analysis. This trains them to connect various pieces of information to build a deeper understanding. Finally, in the conclusion aspect, students are asked to formulate a conclusion based on the analysis, predictions, and interpretations they have made, thus supporting their critical thinking skills in constructing systematic and logical conclusions.

The results of the validation of the developed teaching module can be seen in Table 2, which shows the validity and reliability values of the teaching module assessed by two expert validators and one practitioner validator.

Table 2 Validity and reliability values of the teaching module

Aspect	Validity		Reliability	
	Value	Category	Value	Category
Module Cover Design	3.91	Excellent	89.49%	Reliable
General Information	3.61	Excellent		
Core Components	3.33	Good		
Meeting list details	3.40	Good		
Attachment Details	3.40	Good		
Average	3.53	Excellent		

Based on Table 2, the overall average validity score is 3.54, which is categorized as very good, and the reliability is 89.49%, which is categorized as reliable. Furthermore, the detailed validity and reliability values of the learning achievement test can be seen in Table 3.

Table 3 Validity values of the learning achievement test

Assessment Aspect	Validity		Reliability	
	Average	Category	Average	Category
Instructions for using the questions are clearly stated	3.75	Excellent	89%	Reliable
The questions are aligned with the learning objectives	3.34	Good	93%	Reliable
The scoring guidelines are clear	3.92	Excellent	96%	Reliable
Score Appropriateness	3.75	Excellent	89%	Reliable
The question sentences do not lead to multiple interpretations	3.67	Excellent	86%	Reliable
The questions use straightforward question or command sentences	3.50	Excellent	86%	Reliable
The time for completing the questions is appropriate	3.67	Excellent	86%	Reliable
Using correct Indonesian grammar rules	3.58	Excellent	93%	Reliable
Using easy-to-understand language	3.58	Excellent	89%	Reliable
The questions are suitable for measuring students' critical thinking skills.	3.50	Excellent	86%	Reliable
Average	**3.63**	**Excellent**	**89%**	**Reliable**

Table 3 shows the results of the learning outcome test instrument validation by experts based on 10 assessment aspects. The overall average score was 3.63, which falls into the "Very Good" category. The module developed by the researcher was presented in printed form. The module development is considered valid if it has a validity rating of at least good and is reliable. Reliability in this study refers to the consistency or agreement between the assessments of validators 1, 2, and 3. Based on the validity test conducted by two experts and one practitioner, the results, as shown in Table 3, indicate that the dynamic fluid teaching module, which uses multirepresentation-based guided inquiry to improve students' critical thinking skills and was developed, is categorized as excellent from a content perspective.

Additionally, the reliability results of the developed module are categorized as reliable. Validity is defined as the extent to which an instrument accurately measures what it is intended to measure. A high degree of validity indicates that the developed module aligns with the learning objectives and relevant content, making it feasible for use in schools. In this study, the module's validity results were revised based on the feedback from validators, and necessary improvements were implemented to ensure its readiness for classroom application(Creswell, 2018). The development of valid and reliable teaching materials is a crucial element in enhancing the quality of learning, as it ensures the content's alignment with curriculum standards and the reliability of users in its application. In line with this, it is affirmed that teaching materials must undergo validity testing to ensure the accuracy of concepts and the consistency of material structure before being used in the learning process (Cahyani, 2020). In addition, it is emphasized that the validity assessment process should be carried out through expert evaluation to ensure the accuracy of the content and the relevance of the material, thereby ensuring that the final results of the teaching materials are academically accountable and accepted by both teachers and students (Wulandari & Oktaviani, 2021).

Practicality

The practicality of the module was assessed based on the results of implementing the learning steps in the teaching module, which was conducted over three meetings and observed by three observers. The scores for each aspect were then averaged. The observers completed observation sheets to document the implementation of the learning steps in the teaching module. The following are the results of the practicality test of the module developed by the researcher, and the detailed implementation results can be seen in Table 4.

Table 4 Results of the implementation of the teaching module

Activity	Meeting 1		Meeting 2		Meeting 3	
	Value	Ket	Value	Ket	Value	Ket
Introduction	4.00	SB	4.00	SB	4.00	SB
Problem Orientation	3.80	SB	3.80	SB	3.60	SB
Formulating Hypotheses	3.00	B	3.33	B	3.00	B
Collecting Data	3.00	B	3.50	SB	3.83	SB
Analyzing Data	3.00	B	3.33	B	3.33	B
Drawing Conclusions	3.50	SB	3.83	SB	3.50	SB
Conclusion	3.75	SB	3.92	SB	4.00	SB
Average	3.57					
Category	Very Good					

Explanation: B = Good; SB = Very Good

Table 4 shows the practicality results of the module, with an average of 3.57, categorized as very practical. Overall, the dynamic fluid teaching module, which utilizes multirepresentation-based guided inquiry to enhance students' critical thinking skills, developed by the researcher, is highly practical for use in learning. The practicality of the dynamic fluid teaching module, which utilizes a multirepresentation-based guided inquiry model to enhance students' critical thinking skills, is reviewed based on the implementation sheets of the learning steps in the teaching module. This module was created by referring to the syntax of the guided inquiry model. The use of the guided inquiry model must follow specific syntax to be effective and make it easier for students to follow the learning process. If the module follows this structure, the process can run systematically and be more practical in the classroom. The expected outcomes of the learning activities are to improve students' critical thinking skills and enable them to achieve the desired learning objectives. Therefore, learning using guided inquiry based on multirepresentation, as employed in the developed module, can be applied in classroom learning (Prahani et al., 2016). The guided inquiry model can develop students' critical thinking skills because they are trained to actively ask questions, analyze, draw conclusions, and evaluate throughout the learning process (Istiana et al., 2023).

Effectiveness

The effectiveness of the module is measured using pretest and posttest learning outcomes, which utilize indicators of students' critical thinking skills. Learning outcomes help determine the results of learning before and after instruction using the developed module. The analysis of student learning outcomes, based on pretest and posttest scores, is presented in Table 5.

Table 5 Student learning outcomes data

Pretest		Posttest		N-Gain	
Value	**Category**	**Value**	**Category**	**Value**	**Category**
6.65	Very low	69.83	Currently	0.69	Moderate/Effective

Table 5 shows that the average pretest scores obtained by the students were abysmally low, indicating that their critical thinking skills were still very underdeveloped. This is because they have not yet used a dynamic fluid teaching module based on guided inquiry with multiple representations. The average post-test scores were good, indicating that students' critical thinking skills improved, as they had already studied the material. This is supported by the N-gain score obtained, which falls into the medium/effective category, indicating that the developed module is effective for the learning process. The effectiveness of the learning process can be measured by how well students achieve the predetermined learning objectives. Significant learning outcomes from the pretest and post-test are a key indicator in assessing the success and effectiveness of the module and the methods used. Effectiveness in this context can be defined as the level of students' success in achieving the established learning objectives, which ultimately determines the optimal success of students' learning outcomes. A learning process is considered effective when its implementation follows the correct procedures, utilizes appropriate techniques and strategies, and achieves learning objectives optimally, efficiently, and effectively. In this study, the effectiveness of the teaching module was assessed through pretest and post-test results, which were used to measure students' learning outcomes and critical thinking skills before and after the implementation of the teaching module in the learning process (Sari, 2018). The use of pretests and post-tests is a standard method for measuring learning success and improving students' critical thinking skills. Significantly improved results indicate that this module is practical (Shivaraju et al., 2017).

Achievement of Critical Thinking Skills

Critical thinking skills were assessed using learning outcome tests, which included pretests and posttests. The learning outcome tests consisted of four questions designed to assess critical thinking skills, including interpretation, prediction, analysis, and conclusion. The tests given to students included one question on the interpretation aspect, one question on the prediction aspect, one question on the analysis aspect, and one question on the conclusion aspect. The results of students' achievement in critical thinking skills are presented in Table 6.

Table 6 Achievement of critical thinking skills

No	Aspect	Average Pretest		Average Posttest	
		Value	**Category**	**Value**	**Category**
1	Interpretation	5.90	Very low	83.91	Very high
2	Prediction	0.76	Very low	71.16	Medium
3	Analysis	0.00	Very low	69.72	Medium
4	Conclusion	0.00	Very low	74.09	High

All critical thinking indicators showed improvement after the module was used, as shown in Table 6. However, this improvement occurred differently for each indicator, suggesting that it was related to the learning mechanisms used in each phase of guided inquiry and multirepresentation integration. In the pretest stage, all indicators were in the very low category. However, after the intervention, the interpretation indicator increased the most, reaching the very high category. Students were trained to identify variables, understand the context of dynamic fluid phenomena, and interpret information from various representations (flow diagrams, cross-sectional area-velocity graphs, and verbal

descriptions). The problem orientation phase of the module allowed for this improvement to be explained. In this early stage, inter-representation translation activities helped students understand the physical meaning of the situation before performing mathematical calculations.

Analysis and prediction indicators, also known as inference, rose to the moderate category. This improvement is related to the exploration and data analysis stage. At this stage, students are asked to compare their observations with their initial hypotheses and see whether the tables, graphs, and mathematical equations are consistent. Students are encouraged to find patterns and relationships between variables through a process of multi-representation coordination. However, the low-class results indicate that some students still have difficulty integrating quantitative evidence with conceptual arguments. This is especially true when they are asked to explain why certain mathematical steps are used. The conclusion indicator reached a high category. This is in line with the final phase of learning, where students are explicitly asked to draw conclusions based on data and provide justification using more than one representation. Structured reflection activities and class discussions play a role in strengthening the ability to formulate logical generalizations based on empirical evidence.

The N-gain value of 0.69, which is in the moderate category, indicates that overall the developed module is effective in improving students' critical thinking skills, although the improvement has not yet reached the high category. Mechanistically, this achievement can be explained through several components of learning design that work in an integrated manner, namely the active involvement of students in each phase of inquiry, starting from formulating problems and proposing hypotheses to analyzing data to drawing conclusions. What encourages them to think systematically is the requirement for translation and coordination between representations (verbal, graphic, and mathematical), which forces students to evaluate the consistency of meaning and the relationship between variables, as well as the use of scaffolding questions that gradually guide students towards analysis, evaluation, and evidence-based conclusion-drawing activities. The combination of these three aspects contributes to strengthening critical thinking indicators in dynamic fluid learning.

The differences in the levels of improvement between indicators show that the analysis and evaluation phases require longer practice time and more intensive scaffolding than the interpretation and conclusion-drawing phases. Thus, these findings not only show that the module is effective but also explain how and through what processes the integration of guided inquiry and multirepresentation contributes to the strengthening of critical thinking indicators in the context of dynamic fluids. This finding is consistent with research indicating that guided-inquiry-based teaching materials are effective in enhancing critical thinking skills, although the level of improvement is categorized as moderate. Conceptually, the guided inquiry model facilitates this development through learning stages that direct students to actively formulate problems, propose hypotheses, collect data, analyze findings, and draw conclusions (Rianti, 2021). The relatively short research duration resulted in not all indicators showing a high level of improvement, as students' critical thinking skills require continuous and sustained practice and cannot be optimally developed within only a few learning sessions (Alsaleh, 2020). Inquiry-based learning consists of the phases of orientation, conceptualization, investigation, and reflection, through which students not only understand theoretical concepts but are also able to relate them to real phenomena, such as experiments measuring pressure and flow velocity in dynamic fluid topics (Pedaste et al., 2015).

This process enables students to build knowledge through structured inquiry activities, thereby facilitating the development of their critical thinking skills (Suyidno, 2021).

Previous research indicates that guided inquiry can increase student participation while simultaneously training higher-order thinking skills (Prabandari, 2023). Further findings revealed that a performance assessment-based guided inquiry model is effective in improving high school students' critical thinking skills, as demonstrated by a one-group pretest-posttest design (Iftirani & Sunarti, 2024). Other empirical results show that students' posttest scores on critical thinking are significantly higher than their pretest scores after the application of the model on temperature and heat material (Agustin et al., 2020), and similar improvements were also reported in students at the State Junior High School 9 Palangka Raya (Anggela et al., 2025). Consistent evidence highlights that guided inquiry has a significant influence on students' critical thinking skills in physics when compared to conventional instruction (Harjilah et al., 2019). These changes indicate that the applied instructional method has the potential to enhance student success through the development of critical thinking skills, in line with findings showing that learning strategies emphasizing active student engagement significantly improve learning outcomes (Hasbi et al., 2022). Guided inquiry learning is capable of improving students' scientific thinking skills because it actively involves learners in every stage of the discovery process, from problem formulation to drawing conclusions (Sulistyani et al., 2022). The implementation of guided inquiry in learning activities has been proven to enhance students' critical thinking skills, as learners are encouraged to analyze problems and construct knowledge independently (Maknun, 2020). The application of the guided inquiry model in dynamic fluid topics significantly improves students' scientific literacy, particularly in the competency aspect of interpreting data and scientific evidence, which forms the core of scientific and critical thinking skills (Arifin & Sunarti, 2017). The guided inquiry model is effective in physics learning because it creates an active learning environment, enhances critical thinking skills, and supports students in constructing knowledge independently through a structured scientific process (Drastisianti et al., 2024). In addition, the multi-representation approach plays a crucial role in bridging the understanding of abstract concepts in dynamic fluid topics (Talib & Amiroh, 2022), and studies also report its positive effect on strengthening critical thinking skills (Chrestella, 2021). The use of multi-representational approaches in inquiry-based learning enables students to connect concrete physical phenomena with symbolic and mathematical representations, and students' positive responses indicate that such learning is not only academically effective but also increases engagement and learning interest, making it effective for developing critical thinking skills in senior high school physics learning (Amanati, 2019).

The integration of these two approaches is the main advantage of the developed module product. The module not only presents material but is also designed as a systematic and contextual learning tool, where each activity is aimed at training students to interpret, analyze, evaluate, and draw conclusions. Active engagement in experimental activities enhances students' self-confidence and reflective thinking abilities, highlighting the importance of experiential learning that involves direct experience and reflection, which in turn improves learning outcomes (Bansal et al., 2022).

Improvements in learning outcomes are strongly influenced by the structured stages of guided inquiry, including problem orientation, hypothesis formulation, exploration through simulations, data analysis, and conclusion drawing, which encourage students to independently construct concepts through scientific investigation and significantly develop conceptual understanding, analytical ability, and critical thinking skills (Azis & Ariani, 2025). Thus, the improvement of students' critical thinking skills does not occur solely through repetition of the material but rather through meaningful learning experiences that combine scientific inquiry (guided inquiry) with the exploration of various forms of representation (multirepresentation). Therefore, the success of improving students' critical

thinking skills in this study is inseparable from the role of the guided inquiry and multirepresentation-based teaching module that was developed. The module serves as a facilitator for an active and meaningful learning process, encouraging the development of higher-order thinking skills essential in 21st-century physics education.

CONCLUSION

This research developed a dynamic fluid teaching module based on guided inquiry and multirepresentation, which is valid, practical, and effective in enhancing high school students' critical thinking skills. The uniqueness of the module lies in the integration of two pedagogical strategies: guided inquiry, which guides students through the stages of scientific investigation, and multirepresentation, which presents physics concepts in various formats (verbal, graphical, visual, and mathematical). The synergy of both allows students not only to understand the concepts of fluid dynamics more deeply but also to practice critical thinking skills, particularly in the areas of interpretation, analysis, and drawing conclusions.

Practically, this module can be utilized by teachers as a contextual teaching tool that supports the Merdeka Curriculum, emphasizing real-world problem-based inquiry activities and the presentation of concepts through various forms of representation. For students, the module offers a meaningful learning experience that helps them grasp abstract concepts while also developing their critical thinking skills in problem-solving. Meanwhile, for schools, this module can serve as a reference for developing innovative teaching materials for other abstract physics topics or be combined with digital technology to enrich the learning experience. Thus, this module is not only suitable for use but also makes a real contribution to improving the quality of physics learning and strengthening students' critical thinking skills. However, this study has limitations. The use of a one-group pretest–posttest design without a control group restricts comparative analysis, and the small sample size from a single class limits generalizability. Additionally, the short implementation period does not allow for evaluating long-term effects on students' critical thinking. Future studies should involve broader samples, employ comparative research designs, and examine longer-term learning outcomes.

CONFLICTS OF INTEREST

The authors declare no conflict of interest in this research and article writing.

AUTHOR CONTRIBUTION STATEMENT

The first author contributed to research design, theoretical framework development, and data collection and analysis. The second author was involved in instrument validation, compiling research results, and conducting a literature review. The third author contributed to data interpretation, development of the discussion, and refinement of the manuscript. All authors actively participated in the revision process, provided substantial input, approved the final manuscript, and bear full responsibility for the article's content.

AI DISCLOSURE STATEMENT

The author used Google Scholar, Google Translate, and Grammarly to search for and identify reference sources, translate text, and improve the structure of the English. The author thoroughly reviewed and edited the article's content as needed and takes full responsibility for the published content. Furthermore, this article was prepared, researched, written, and edited without the use of artificial intelligence techniques.

ACKNOWLEDGMENTS

The authors express gratitude to the validators, practitioners, and the staff of SMA Negeri 1 Banjarmasin for granting permission and providing support in the implementation of this research.

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