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FlowMaster: A Gamified Media Based on Discovery Learning for Developing Critical Thinking Skills on the Concept of Dynamic Fluids

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Abstract: This study aims to develop FlowMaster, a gamified instructional media explicitly designed with interactive simulations, Discovery Missions, adaptive feedback, and problem-based challenges to support discovery learning in the topic of Dynamic Fluids. The development of this media is grounded in the need to enhance students' critical thinking skills, which remain insufficiently fostered through conventional teacher-centered instruction and static learning media. The research adopts a Research and Development (R&D) approach using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). The study involved 60 eleventh-grade science students from SMA Negeri 9 Semarang, divided into an experimental group (using FlowMaster) and a control group (using conventional media). Expert validation indicated a very high level of feasibility in terms of media design (93.33%) and high feasibility in terms of content quality (81.11%). The effectiveness test, using a quasi-experimental design, revealed a significant improvement in students' critical thinking skills in the experimental group (N-Gain = 0.779; high category), outperforming the control group (N-Gain = 0.659). Further analysis showed that the media's key features—particularly Discovery Missions and interactive simulations—effectively supported decision-making skills (N-Gain = 0.78) and the ability to provide simple explanations (N-Gain = 0.85). These findings suggest that FlowMaster, as a gamified discovery-based learning media with clearly defined interactive and cognitive scaffolding features, provides an innovative and effective solution for promoting students' cognitive engagement and critical thinking skills, in line with the demands of 21st-century education.

Keywords: Gamified media; Discovery learning; Critical thinking; Dynamic fluids; FlutterFlow

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Introduction

Critical thinking has become a fundamental competency in science education in the era of the Fourth Industrial Revolution, particularly in equipping students to address complex and authentic scientific problems. Contemporary science education research emphasizes that science literacy extends beyond the mastery of concepts to include the ability to analyze information, evaluate evidence, and apply knowledge in real-world contexts (OECD, 2023; National Academies of Sciences, 2022). These competencies are closely կապված with analytical and problem-solving skills, which are inherently rooted in critical thinking processes.

However, numerous studies indicate that conventional physics instruction, which predominantly focuses on rote memorization and procedural problem-solving, remains insufficient for developing these higher-order thinking skills (Halim et al., 2023; Docktor & Mestre, 2021). This issue is reflected in the Programme for International Student Assessment (PISA) 2022 results, where Indonesian students ranked 74th out of 81 participating countries in science literacy, with an average score of 383, significantly below the OECD average (OECD, 2023). Such findings suggest that students face difficulties not only in understanding scientific concepts but also in analyzing problems, constructing explanations, and making evidence-based decisions.

These challenges become more pronounced when students encounter abstract physics topics, such as dynamic fluids, which require deep conceptual understanding, multi-representational thinking, and the integration of theoretical and practical knowledge (Kaniawati et al., 2022). At the level of instructional practice, evidence shows that physics teaching in many Indonesian classrooms still relies heavily on teacher-centered approaches and static instructional media, limiting opportunities for active learning and critical engagement (Widodo et al., 2023).

A preliminary study conducted at SMA Negeri 9 Semarang supports this condition, revealing that 82% of physics instruction still depends on conventional PowerPoint-based delivery, with only a small proportion of students actively engaged in higher-order thinking activities. The dominance of static media (85%) and low engagement in critical thinking tasks (15%) indicate a significant gap between current instructional practices and the competencies required for 21st-0century learning. This gap persists despite the availability of digital infrastructure, suggesting that the issue lies not in access to technology but in the lack of pedagogically meaningful integration (Makhula et al., 2024).

From a theoretical perspective, constructivist learning theory highlights discovery learning as an effective approach for fostering critical thinking by encouraging students to actively construct knowledge through exploration and inquiry (Bruner, 2017). Recent empirical studies demonstrate that discovery-based learning significantly improves conceptual understanding and cognitive engagement compared to traditional approaches (Furtak et al., 2022; Chen et al., 2023). Nevertheless, its implementation in classroom settings is often constrained by the absence of interactive and supportive learning media that can guide students' exploration effectively.

In parallel, advancements in educational technology have shown that gamification can enhance students' motivation, engagement, and persistence in learning activities when appropriately integrated with pedagogical approaches (Deterding et al., 2023; Sailer & Homner, 2020). However, existing studies often treat gamification and discovery learning as separate approaches, leaving a gap in the development of integrated learning media that combine both strategies in a coherent and pedagogically meaningful way.

To address this gap, low-code development platforms such as FlutterFlow offer new opportunities for creating interactive and accessible learning media. These platforms enable educators to design applications with rich interactive features—such as simulations, feedback systems, and adaptive tasks—without requiring advanced programming expertise (Zrinscak et al., 2024; Aldalur & Perez, 2023). This capability makes them particularly suitable for supporting discovery learning environments that demand high levels of interactivity and student engagement.

Based on these considerations, this study focuses on developing FlowMaster, an innovative learning medium characterized by the integration of discovery learning principles with gamification features, including interactive simulations, Discovery Missions, adaptive feedback, and problem-based challenges, developed using the FlutterFlow platform. The study addresses three primary objectives: (1) to evaluate the validity and reliability of FlowMaster as a learning medium, (2) to examine its effectiveness in enhancing students' critical thinking skills, and (3) to identify which critical thinking indicators, based on Ennis' (2015) framework—such as providing reasons, identifying assumptions, drawing conclusions, interpreting statements, and evaluating arguments—show the most significant improvement.

This research contributes both theoretically and practically. Theoretically, it advances the literature on the integration of low-code technology, gamification, and discovery learning in science education. Practically, it provides an adaptable prototype of interactive learning media that can support physics teachers in implementing student-centered learning approaches. The findings are expected to inform the development of more responsive science education practices and policies aligned with the demands of 21st-century competencies.

Methods

This study employs a Research and Development (R&D) approach by adopting the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) to develop the FlowMaster media (Sugiyono, 2015). The initial stage of the research involved a needs analysis through an in-depth literature review and field observations at SMA Negeri 9 Semarang. These findings served as the basis for designing a

FlutterFlow-based instructional media that integrates the principles of discovery learning and gamification elements to create an interactive learning experience.

The research subjects consisted of 60 eleventh-grade students who selected physics as their elective subject. Participants were chosen using purposive sampling, considering the equivalence of their pretest scores and learning characteristics. The students were divided into two groups: an experimental group (n = 30) that used the FlowMaster learning media, and a control group (n = 30) that used conventional PowerPoint-based media. The study employed a quasi-experimental design with a pretest-posttest control group format to evaluate the effectiveness of the media in enhancing students' critical thinking skills.

The research instruments consisted of expert validation sheets for assessing the feasibility of both media and content, a critical thinking ability test in the form of 10 essay questions, and a student response questionnaire (Cresswell, 2018). The media expert validation sheet evaluates aspects of software engineering, instructional design, and visual communication. Meanwhile, the content expert validation focuses on the appropriateness of the material and its alignment with the critical thinking indicators proposed by Ennis (2015). The critical thinking ability test has undergone validation processes to ensure its reliability ($\alpha = 0.98$), as well as assessments of item difficulty and discrimination index.

The development process of the media involved formative evaluation during the Development phase to refine the product based on feedback from expert validators. Implementation was carried out over four sessions using a discovery learning approach, where students explored the concept of Dynamic Fluids through interactive features such as Discovery Missions and virtual simulations. Data analysis employed a paired-sample t-test and N-Gain to assess improvements in critical thinking skills, complemented by qualitative analysis of student responses and classroom observation notes. All statistical analyses were performed using SPSS 25, with the paired-sample t-test yielding a significance value of $p < 0.05$, indicating that the observed improvements in students' critical thinking skills were statistically significant.

This study adheres to academic ethical standards by ensuring participant data confidentiality and obtaining approval from relevant institutions. Internal validity was maintained through strict control of confounding variables, such as the equivalence of instructional materials and the duration of learning between the experimental and control groups.

Results and Discussion

The results of this study are presented based on the research objectives, including the validity of the media, its effectiveness in improving critical thinking skills, and the analysis of critical thinking indicators.

First, the validity of FlowMaster was evaluated through expert judgment covering media and content aspects. The validation results show that the media aspect achieved a score of 93.33%, categorized as very valid, while the content aspect obtained a score of 81.11%, categorized as valid. These results indicate that FlowMaster meets the feasibility criteria for use as an instructional medium.

Second, the effectiveness of FlowMaster in enhancing students' critical thinking skills was examined using N-Gain analysis. The experimental group achieved an N-Gain score of 0.779, which falls into the high category, while the control group obtained a score of 0.659, categorized as medium. This finding suggests that the use of FlowMaster contributes to a greater improvement in students' critical thinking skills compared to conventional learning media.

Third, further analysis was conducted on each indicator of critical thinking based on Ennis' framework. The results indicate that the highest improvement was observed in the ability to provide simple explanations (N-Gain = 0.85), followed by decision-making skills (N-Gain = 0.78). These findings demonstrate that specific features in FlowMaster, such as Discovery Missions and virtual laboratory simulations, effectively support students' engagement in higher-order thinking processes.

These findings are consistent with previous studies highlighting the role of interactive and discovery-based learning environments in promoting critical thinking. The integration of gamification elements and interactive simulations in FlowMaster provides opportunities for students to actively explore concepts, which aligns with constructivist learning principles (Bruner, 2017). Furthermore, the use of FlutterFlow as a development platform supports the creation of responsive and interactive learning environments, as also emphasized in recent studies (Zhang et al., 2024).

A comparative visualization of the improvement in critical thinking skills between the experimental and control groups is presented in Figure 1.

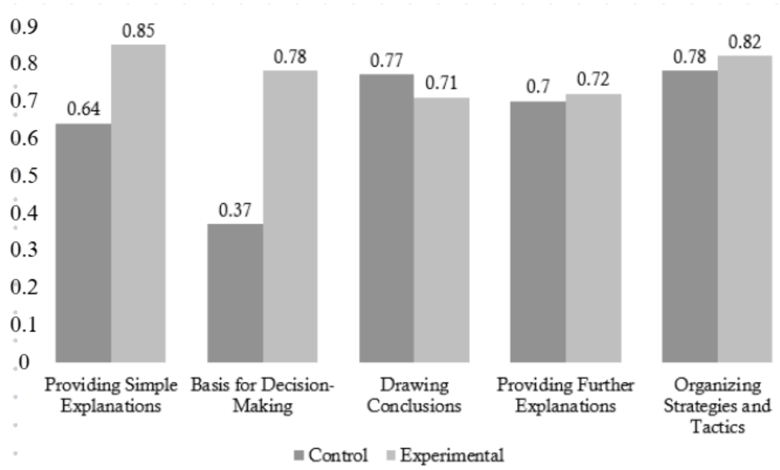

Figure 1. Comparison Diagram of N-Gain Test Results of Pretest and Posttest Values between Experimental Group and Control Group

The improvement in students' critical thinking skills was analyzed using the N-Gain score, as presented in Table 1.

Table 1. N-Gain Scores of Critical Thinking Indicators

Critical Thinking Indicator	Control Group	Experimental Group	Category (Exp.)
Providing Simple Explanations	0.64	0.85	High
Basis for Decision-Making	0.37	0.78	High
Drawing Conclusions	0.77	0.71	High
Providing Further Explanations	0.70	0.72	High
Organizing Strategies and Tactics	0.78	0.82	High
Average N-Gain	0.65	0.78	High

The results indicate that the experimental group achieved a higher average N-Gain score (0.78) compared to the control group (0.65), both categorized as high and medium respectively. Among the indicators, the highest improvement in the experimental group was observed in "providing simple explanations" (0.85), followed by "organizing strategies and tactics" (0.82) and "basis for decision-making" (0.78). In contrast, the lowest improvement occurred in "drawing conclusions" (0.71), although it still falls within the high category. These findings suggest that the use of FlowMaster effectively supports students in structuring their understanding and engaging in higher-order thinking processes, particularly in explaining concepts and making decisions. This is likely influenced by the integration of Discovery Missions and interactive simulations, which provide opportunities for active exploration and problem-solving.

Classroom observation data on student participation during the learning process are presented in Table 2.

Table 2. Student Participation Levels During Learning Activities

Aspect of Participation	Control Group (%)	Experimental Group (%)
Asking questions	45	78
Responding to questions	50	80
Engaging in discussions	48	82
Completing tasks actively	55	85
Average Participation	49.5	81.25

Based on Table 2, the experimental group demonstrated a higher level of participation, with an average of 81.25%, compared to 49.5% in the control group, indicating a substantial increase in student engagement during the learning process. In addition, the analysis of critical thinking indicators shows that most indicators improved significantly in the experimental group (see Table 1). However, the "drawing conclusions" indicator showed a slightly lower N-Gain in the experimental group (0.71) compared to the control group (0.77).

This finding suggests that while FlowMaster effectively enhances student engagement and supports various aspects of critical thinking, certain cognitive processes—such as drawing conclusions—may require more structured guidance. One possible explanation is that conventional linear media, such as PowerPoint presentations, provide a more sequential flow of information, which may support students in integrating concepts more systematically (Wardhana et al., 2024).

Furthermore, the increased participation observed in the experimental group may be influenced by the gamification features embedded in FlowMaster, such as leaderboards and reward systems, which can enhance students' motivation and engagement in learning activities, consistent with the principles of Self-Determination Theory (Saputri et al., 2024).

From a pedagogical perspective, the success of FlowMaster can be attributed to three key factors. First, its alignment with the characteristics of Generation Z, who tend to be highly responsive to digital technologies (Inigo, 2023). Second, the effective application of scaffolding through context-aware support features embedded within the platform. Third, the integration of visual elements, interactivity, and conceptual content that together foster a holistic learning experience. The positive response from 93% of students regarding ease of use and content relevance reinforces the findings of Hommer et al. (2019), emphasizing the importance of user-centered design in the development of educational media.

This study also identified several limitations that warrant further attention. First, the adaptability of the media to accommodate students with varying learning styles still needs improvement. Second, the availability of infrastructure in some schools may pose a challenge to broad implementation. Third, the learning curve for teachers in operating this new media necessitates dedicated support and guidance. These findings are consistent with the report by Bilad et al. (2024), which highlights the challenges of implementing educational technology in Indonesia.

Theoretically, this study makes a significant contribution to the development of the TPACK (Technological Pedagogical Content Knowledge) framework, specifically tailored for modern physics education. Practically, FlowMaster presents a concrete model of how the discovery learning approach can be effectively integrated with accessible low-code technologies. The successful implementation of this media opens up opportunities for developing similar variants for other physics concepts. It also serves as a reference point in shaping science education policies in the digital era.

Conclusion

This study convincingly demonstrates that the FlowMaster media, developed using FlutterFlow with a discovery learning and gamification approach, significantly enhances students' critical thinking skills on the topic of Dynamic Fluids. This is evidenced by highly favorable expert validation results (media: 93.33%, content: 81.11%) and a high N-Gain score of 0.779, which notably exceeds that of the control group (0.659). The most substantial improvements were observed in the development of the indicators "providing simple explanations" (N-Gain: 0.85) and "decision-making" (N-Gain: 0.78). These findings also demonstrate the effectiveness of low-code platforms in creating affordable and easily adoptable interactive learning media that meet the demands of 21st-century education.

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