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Development of FluidInsight: A PBL-Based Mobile Learning Application for Static Fluids

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ABSTRACT

The scarcity of interactive media in static fluid topics often poses difficulties in engaging high school students actively and comprehensively. This study seeks to develop FluidInsight, a Problem-Based Learning (PBL)-based Android application created via the Kodular platform to improve student learning outcomes. The research followed a Research and Development (R&D) design using the 4D model, specifically limited to the Develop stage. Participants included 28 eleventh-grade students involved in a one-group pretest-posttest design. Expert validation yielded an average score of 85.6% (highly feasible), while practicality testing through the User Experience Questionnaire (UEQ) showed high ratings in the stimulation (2.143) and attractiveness (2.036) dimensions. The effectiveness test demonstrated an improvement in learning outcomes with an average N-gain score of 0.55 (moderate). These findings indicate that FluidInsight effectively visualizes abstract concepts and facilitates student-centered learning. Therefore, the integration of PBL into Android-based media serves as an innovative digital transformation strategy for physics instruction.

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1. INTRODUCTION

Effective physics instruction in the 21st century necessitates a profound conceptual understanding where students actively construct knowledge through discovery and mental engagement, rather than mere rote memorization (Lestari et al., 2025). In line with constructivist learning theory, students must mentally build their own knowledge structures based on their cognitive maturity, positioning them not as passive recipients of information but as active participants in the learning process (Sutisna, 2013). This perspective emphasizes that meaningful learning occurs when new information is integrated with existing cognitive frameworks through active manipulation of ideas. However, a significant gap persists between this pedagogical ideal and the actual learning outcomes observed in secondary education. The existing learning problems are particularly evident in topics involving high levels of abstraction and mathematical complexity, such as static fluids. Empirical data indicate that students consistently struggle to internalize fundamental laws, with more than 50% of learners failing to meet minimum mastery standards. (Wulandari & Perdana, 2023).

These challenges are significantly exacerbated by the limitations of current instructional media. Preliminary observations reveal that physics instruction in many schools is still heavily dominated by static printed textbooks and non-interactive presentation tools, such as PowerPoint.

While these resources provide theoretical information, they lack the dynamic interactivity required to bridge the gap between abstract physics concepts such as hydrostatic pressure, Pascal's Law, and Archimedes' Principle and their real-world applications (Sitinjak et al., 2024). Traditional media fail to provide the cause-and-effect feedback loop necessary for scientific inquiry. For instance, a textbook cannot show the proportional change in buoyancy as an object is submerged, nor can it simulate the varied pressures at different depths in real time. This lack of visualization leaves students unable to conceptualize fluid mechanics as a dynamic system, resulting in a fragmented understanding where formulas are memorized without a grasp of the underlying physical intuition. Consequently, students often remain passive observers, leading to low classroom participation and a lack of motivation to explore physics beyond the classroom.

To address these pedagogical barriers, the importance of implementing Problem-Based Learning (PBL) cannot be overstated. PBL serves as a robust framework that positions students as active investigators who construct knowledge by solving authentic, real-world problems. In the PBL model, the learning process begins with a complex, ill-structured problem that mimics the challenges faced by professional scientists and engineers. This approach encourages students to engage in high-level cognitive processes, including analysis, synthesis, and evaluation (Ahmad, 2024). By shifting the focus from teacher-centered lectures to student-centered inquiry, PBL fosters the critical thinking and autonomy necessary for mastering complex subjects (Khairunnisa et al., 2025). In the context of static fluids, a PBL approach allows students to explore the why and how behind physical laws, such as investigating the structural integrity of dams or the mechanics of hydraulic machinery. This methodology transforms abstract formulas into meaningful solutions, ensuring that students do not just learn about physics but learn how to do physics through systematic investigation and evidence-based reasoning.

The rationale for using the Kodular platform in this study lies in its strategic ability to support the digital implementation of the PBL model. Kodular is a sophisticated web-based platform that enables the development of high-performance Android applications through an intuitive block-programming interface, eliminating the technical overhead of traditional coding (Permatasari et al., 2023). This accessibility allows developers to focus entirely on pedagogical design and user experience. Specifically, Kodular supports the integration of comprehensive multimedia features such as video case studies for problem orientation, interactive simulations for data collection, and real-time feedback modules, which are essential for facilitating the five stages of PBL. Furthermore, the platform's ability to handle high-resolution imagery and smooth animations is critical for visualizing static fluid concepts. By utilizing Kodular, this research develops FluidInsight, a portable learning environment that ensures students can engage with physics content anytime and anywhere, effectively extending the learning experience beyond the physical boundaries of the school laboratory.

Furthermore, the novelty and contribution of this developed application are significant when compared to previous studies. While earlier research, such as that by (Wiandari et al., 2023) or (Batubara, 2021), has successfully explored digital media for physics, many of these tools focus primarily on static content delivery or digitized versions of traditional modules. These applications often lack a reciprocal interaction where the student's input directly influences the learning path. In contrast, FluidInsight distinguishes itself by systematically embedding the complete PBL syntax from the initial problem orientation to the final evaluation directly into a synchronized mobile interface. The application does not merely present information; it scaffolds the entire inquiry process, providing students with the necessary tools to hypothesize, simulate, and conclude their findings within a single digital ecosystem. By harmonizing the portability of Android technology with the rigorous inquiry process of PBL, this study contributes an innovative solution to the digital transformation of physics instruction.

In conclusion, the development of FluidInsight addresses a critical need for interactive, student-centered media in the study of static fluids. By integrating advanced mobile technology with the PBL framework, this research seeks to bridge the gap between theory and practice, ultimately enhancing the cognitive outcomes and engagement of eleventh-grade students. Building upon the identified gaps in existing instructional resources, this study focuses on the rigorous development, validation, and testing of FluidInsight. The primary objective is to evaluate the application's

effectiveness in a real-world classroom setting, providing empirical evidence of its ability to foster a deeper understanding of fluid mechanics. Through this approach, the research aims to provide a scalable model for how mobile applications can be used to facilitate complex pedagogical models in science education, ensuring that students are better prepared for the technological and analytical demands of the modern world.

2. METHODS

2.1. Research Design

The research methodology used in this study is Research and Development (R&D). According to (Sugiyono, 2013), R&D is a research method utilized to generate new products and subsequently validate their effectiveness. Research and development have several models; the 4D model is one of the most widely recognized. This Study used the 4D development framework, which has four systematic stages as described by (Thiagarajan, 1974): Define, Design, Develop, and Disseminate (Wijaya et al., 2023). However, due to time constraints, this research is limited to the first three stages of the 4D model. The Disseminate stage is restricted to the specific school where the research was conducted. The Define stage involves analyzing learning problems, student needs, and curriculum objectives related to static fluids. This is followed by the Design stage, which focuses on constructing the application prototype, including UI design in Kodular and the integration of PBL-based storyboards. In the Develop stage, the product undergoes expert validation and field testing to evaluate its effectiveness. The procedures for developing FluidInsight are presented in **Figure 1.**



Figure 1. Systematic stages 4D (Khairi & Ikhsan, 2022)

A rigorous clarification must be established regarding the final stage: the formal "Disseminate" stage was completely omitted from the research design. The implementation of the application within the target classroom was conducted strictly as a localized operational field test under the "Develop" stage to gather practicality and effectiveness data, rather than an expansive dissemination protocol.

The specific developmental procedures carried out within the three stages are detailed as follows:

1. Define Stage: This phase involved analyzing fundamental learning problems, high school curriculum requirements, and student cognitive needs regarding fluid mechanics. The investigation confirmed a critical necessity for interactive digital modules capable of contextualizing theoretical equations into real-world phenomena.
2. Design Stage: This phase focused on constructing the application prototype, including the physical user interface (UI/UX) layout within the Kodular environment, the creation of interactive vector assets, and the systematic mapping of the Problem-Based Learning (PBL) syntax into the media's navigation flow.
3. Develop Stage: This final phase comprised the expert validation process to ensure material and media quality, followed by iterative revisions and an operational field test within a real-world classroom environment to quantify user perception and pedagogical impact.

2.2. Participant and Sampling Rationale

The subjects of this research were 28 eleventh-grade high school students. The data collection techniques implemented include validity, effectiveness, and practicality tests. The validity test was conducted using expert validation sheets to determine the feasibility and functionality of the developed learning materials. The effectiveness test employed pretest and posttest instruments to measure the improvement in student learning outcomes after using the materials. Furthermore, the

practicality test was carried out using the User Experience Questionnaire (UEQ) to evaluate the practical utility and user experience of the developed learning resources (Schrepp, 2023).

To evaluate the instructional effectiveness of the application, this study implemented a Pre-Experimental One-Group Pretest-Posttest Design. The justification for selecting this single-group experimental model rather than a traditional randomized control-group design stems from severe institutional constraints. The school administration did not permit the redistribution or disruption of existing classroom cohorts to prevent scheduling conflicts and preserve instructional continuity under the current curriculum. By utilizing a single group that serves as its own control, the research could closely monitor individual cognitive shifts from the baseline pretest to the final posttest, directly resulting from the application's implementation.

2.3. Instruments and Data Collection Procedures

Data collection was structured around three key parameters: validity, practicality, and effectiveness. To demonstrate the alignment between the underlying research objectives and the evaluation metrics, the instrument framework is mapped out in Table 1.

Table 1. Alignment Matrix of Research Objectives and Assessment Instruments

Research Parameter	Evaluation Dimension	Specific Measured Indications	Total Item
Product Validity	Validation of the Test Instrument	Alignment with curriculum standards (KI/KD), Accuracy of physics concepts, Proportional representation of sub-topics, Clarity of the question stem, and Absence of ambiguous phrasing.	30 Items evaluated via CVR & I-CVI
	Subject Matter Expert Evaluation	Content accuracy, curricular alignment, PBL syntax integration, and clarity of explanations.	10 Items (Likert-5)
	Media & Language Design Evaluation	Interface layout, text legibility, navigation ease, simulation responsiveness, and stability.	26 Items (Likert-5)
Product Practicality	Pragmatic Quality (UEQ)	Efficiency, Perspicuity (Clarity), Dependability (Predictability).	12 Items (Semantic Differential)
	Hedonic Quality (UEQ)	Attractiveness, Stimulation, Novelty.	14 Items (Semantic Differential)
Product Effectiveness	Student Cognitive Outcome	Conceptual mastery of hydrostatic pressure, Pascal's Law, and Archimedes' Principle.	30 Multiple Choice Questions

The cognitive test instrument, consisting of 30 multiple-choice questions targeting static fluid concepts, underwent a rigorous quantitative validation process before field administration. To mathematically verify the content validity of the instrument without causing evaluation bias within the single experimental group, the evaluation data from the expert panel were analyzed using the Content Validity Ratio (CVR) and Item-Content Validity Index (I-CVI) formulated by (LAWSHE, 1975) and (LYNN, 1986). Based on the ratings from the independent validators, the test items achieved a mean I-CVI score of 0.956, falling firmly into the Highly Relevant category. Because the structural integrity, relevance, and conceptual accuracy of the items were explicitly guaranteed through this high mathematical expert consensus, independent statistical reliability testing on a separate trial cohort was omitted, and the instrument's stability was anchored directly to this pre-validated psychometric framework.

The formula used to calculate the Content Validity Ratio (CVR) is as follows:

$$CVR = \frac{n_e - \frac{N}{2}}{\frac{N}{2}} \quad (1)$$

(Iwan Permana Suwarna & Dzakiyy Ilmi, 2016)

Table 2. Validity Criteria

Validity Score (%)	Description
80-100	Very Feasible
60-80	Feasible
40-60	Fairly Feasible
20-40	Not Feasible
<20	Very Unfeasible

(Arikunto, 2009)

2.4. Expert Validation Framework

The structural and conceptual validation of the FluidInsight application and its assessment instruments involved a panel of three independent expert validators. The panel comprised senior university lecturers and physics education specialists holding advanced degrees, equipped with expertise in digital pedagogy, constructivist instructional design, and high school curriculum alignment. This specialized panel ensured that the developed physics material, problem-solving prompts, and assessment items were fully optimized to match the operational cognitive load of eleventh-grade students.

2.5. Data Analysis and N-Gain Criteria

The improvement of student conceptual understanding was quantitatively measured using the normalized gain score (g), as formulated by (Hake, 1998). The mathematical calculation compares the actual gain achieved by the student against the maximum possible gain, represented by the following equation:

$$N - Gain = \frac{posttest\ score - pretest\ score}{ideal\ score - pretest\ score} \times 100\% \quad (2)$$

(Herayanti & Habibi, 2017)

To evaluate the effectiveness level of the medium, the calculated N-gain values are categorized using strict mathematical boundaries to prevent overlapping criteria

Table 3. Effectiveness Level Criteria

N-Gain Score	Category	Effectiveness Interpretation
$g \geq 0{,}7$	High	Effective
$0{,}3 \leq g < 0{,}7$	Moderate	Quite Effective
$g < 0{,}3$	Low	Less Effective

(Richard Hake, 1999)

3. RESULT AND DISCUSSION

3.1 Results

3.1.1 The Implementation of Problem-Based Learning (PBL) in FluidInsight Framework

The development of the FluidInsight application on the Kodular platform resulted in an interactive, Android-based mobile learning module that explicitly embeds the syntax of Problem-Based Learning (PBL). The application transitions traditional static textbook materials into dynamic, problem-driven digital nodes.

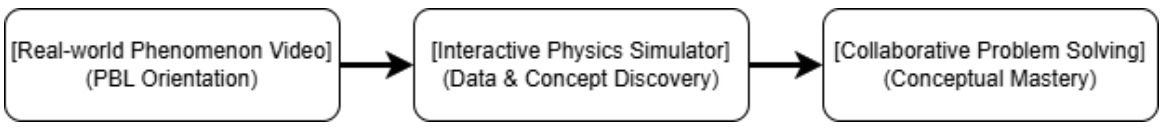


Figure 2. Syntax of the framework

Within the application interface, the initial PBL phase, Orientation of student to the problem, is operationalized through an embedded media player displaying high-definition videos of real-world static fluid anomalies, such as the buoyancy mechanisms of submarines or the force multiplication in hydraulic car lifts. This feature forces students to engage with a practical problem context before moving to abstract algebraic representations. The application utilizes Kodular's native user-interface components to lock theoretical content until the student completes the initial problem-driven navigation sequence, thereby digitally enforcing the constructivist learning flow in a classroom setting.

3.1.2 Expert Validation Analysis of the FluidInsight Application

Expert validation questionnaires were employed to validate the feasibility of the developed product. These questionnaires were validated by several subject matter experts, including content experts, media experts, and linguistics experts. The expert validation instrument in this study utilized a rating scale. A rating scale is an evaluative metric that represents numerical values assigned to specific judgmental outcomes (Rahman & Nasryah, 2019). The assessment within the rating scale consists of five categories: 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), and 1 (Very Poor). Furthermore, experts may provide additional suggestions or feedback in the comments section, which serves as a basis for refining and improving the developed product.

In the feasibility study, the aspects of content, media, and language were evaluated through a validation process conducted by experts. Following the feedback and suggestions provided, revisions were made to the product to ensure that the developed 'FluidInsight' e-module is suitable for use in physics education. The validation results indicated that the media achieved feasibility scores of 83% for the content aspect, 84% for the media aspect, and 90% for the language aspect, with an overall average score of 85%. Based on the assessment criteria, these three aspects are categorized as "Highly Feasible" (Sugiyono, 2013). This validation indicates that the developed learning media are capable of supporting the improvement of student learning outcomes. This enhancement is primarily influenced by the depth of the static fluid material presented, the clarity of instructions aligned with the Problem-Based Learning (PBL) syntax, and the interactive media interface delivered through the Kodular platform.

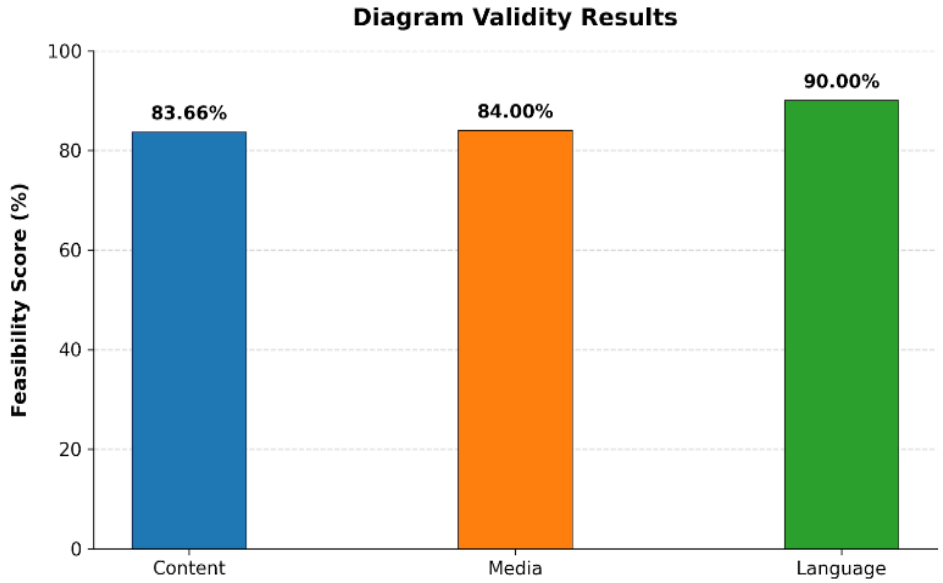


Figure 3. Diagram Validity Results

The distribution of these validation scores is visualized in Figure 3. The exceptionally high score in the language aspect (90%) suggests that the instructional delivery within the e-module is linguistically accessible and pedagogically sound for eleventh-grade students. Furthermore, the

strong alignment between content and media scores indicates a harmonious integration of static fluid concepts within the Kodular-based interface.

3.1.3 Instrument Validity Analysis

Prior to evaluating the instructional effectiveness of FluidInsight in the classroom, the 30 multiple-choice questions designed to measure student cognitive outcomes were subjected to a quantitative content validation process. A panel of three independent expert validators evaluated each test item on a scale of 1 to 5 based on curricular alignment, conceptual physics accuracy, and construct clarity. The empirical data generated from this expert judgment matrix were calculated using Lawshe's Content Validity Ratio (CVR) and Lynn's Item-Content Validity Index (I-CVI).

The psychometric evaluation revealed that the assessment instrument achieved an outstanding mean I-CVI score of 0.956, positioning the entire test framework firmly within the Highly Relevant category. This high expert consensus mathematically confirms that the 30 test items are structurally and conceptually sound, ensuring that the final instrument is highly precise in tracking the student cognitive shifts during the pretest and posttest phases without introducing psychometric measurement bias.

3.1.4 Cognitive Learning Outcomes and N-Gain Distribution

According to (Corcoran, 2005), Hake's N-gain test is employed to measure the extent of student understanding following the implementation of the learning process. The 'gain' represents the difference between the posttest and pretest scores; thus, the N-gain test is utilized to determine the enhancement of student comprehension after instruction. The utilization of Normalized Gain (N-gain), as popularized by Richard Hake, is superior to simple gain scores because it accounts for the 'ceiling effect.' A simple gain score (posttest minus pretest) often biases against students who started with higher pretest scores, as they have less room for improvement.

In the effectiveness test, the improvement in student learning outcomes was analyzed using the Normalized Gain (N-Gain) test. The calculation yielded an N-Gain score of 0.55, which falls into the 'moderate' category (Sukarelawan et al., 2024). The findings demonstrate that the implementation of the learning media significantly enhanced student performance. This is evidenced by the increase in mean scores, rising from a pretest average of 62.79 to a posttest average of 83.57. This reflects an improvement in student learning outcomes in accordance with the theory of (Anderson & Krathwohl, 2001) and is aligned with the objectives of media development.

Table 4. Descriptive Statistics of Student Learning Outcomes

Assessment Stage	N	Mean Score
Pretest	28	62.79
Posttest	28	83.57
Gain Score	-	+20.78
N-Gain Score	-	0.55 (Moderate)

As presented in Table 4, the descriptive statistics highlight a substantial shift in student competency levels. The minimum score increased from 62.79 to 83.57, while the standard deviation indicates a more uniform distribution of understanding post-intervention. The N-Gain score of 0.55 further substantiates that 'FluidInsight' provides a consistent cognitive bridge, facilitating the transition from conceptual confusion to mastery of complex fluid principles.

3.1.5 User Experience Questionnaire (UEQ) Evaluation Scale

Student responses to the learning media were evaluated using a questionnaire to obtain supporting data regarding the practicality aspect of the product. This instrument was administered to the research subjects following the completion of the entire series of learning activities. Through this questionnaire, students provided subjective assessments related to their learning experiences with the static fluid material, which was integrated with the Problem-Based Learning (PBL) model. In this research, the questionnaire employed was the User Experience Questionnaire (UEQ).

The Practicality of the FluidInsight e-module was assessed using the User Experience Questionnaire (UEQ) instrument, which comprises six dimensions: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty (Schrepp, 2023). The assessment results demonstrated significantly positive scores across all aspects, signifying that the e-module is both practical and suitable for implementation as an effective instructional medium. The results of the analysis indicate that the attractiveness dimension achieved a score of 2.036, the perspicuity dimension followed with a score of 1.982, the efficiency dimension scored 1.688, the dependability dimension scored 1.750, the stimulation dimension achieved the highest score, reaching 2.143, and the Novelty dimension recorded the lowest score, 1.616, in comparison to the other five UEQ dimensions. Although the novelty dimension yielded the lowest score, the e-module development emphasizes material clarity and contextual relevance rather than focusing solely on visual originality.

Table 5. UEQ benchmark

Short UEQ Scales		Var	Comparison to benchmark
Attractiveness	2,036	0,64	Excellent
Perspicuity	1,982	1,07	Excellent
Efficiency	1,688	1,10	Excellent
Dependability	1,750	0,88	Excellent
Stimulation	2,143	0,95	Excellent
Novelty	1,616	1,20	Excellent

The UEQ results are graphically represented in Table 5. The 'Stimulation' dimension, which achieved the highest score (2.143), indicates that FluidInsight successfully motivates students to explore physics material further. Conversely, while 'Novelty' received the lowest relative score (1.616), it still falls within the excellent benchmark. This suggests that students prioritized the functional reliability and instructional clarity of the PBL-based module over purely aesthetic innovation. Concurrently, the high Attractiveness rating reflects the user interface (UI/UX) optimization executed in Kodular. By maintaining a clean visual hierarchy, minimizing navigational clutter, and color-coding fluid variables, the system heavily reduced the external cognitive load.

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Figure 4. Eleventh-grade physics students are utilizing the Android-based "FluidInsight" mobile learning application.

To evaluate how the proposed framework operates in a live educational setting, an operational field test was conducted. As visually demonstrated in Figure 4, students independently interacted with the FluidInsight mobile software. During this observation phase, learners showed high engagement when manipulating the interactive fluid variables and observing the real-time physical animations on their personal smartphones. This qualitative behavioral observation directly complements the high empirical ratings recorded in the UEQ stimulation scale and aligns with the significant shift observed from the pretest to the posttest cognitive benchmarks.

3.2 Discussion

The empirical findings of this study demonstrate a significant improvement in students' learning outcomes following the implementation of the FluidInsight mobile application based on Problem-Based Learning (PBL). In contrast to conventional teacher-centered approaches, this Android-based instructional media shifts the pedagogical paradigm by facilitating active student engagement at every stage of the constructivist learning process. This cognitive growth is evidenced by a Normalized Gain (N-Gain) score of 0.55, which formally classifies the improvement in students' conceptual understanding within the "moderate" category ($0{,}3 \leq g < 0{,}7$). From a deeper pedagogical perspective, this moderate shift indicates that the application effectively bridges abstract fluid mechanics with students' cognitive schemas. In static fluids, physics students frequently battle deeply rooted misconceptions, particularly the persistent difficulty in differentiating between the density of the fluid (ρ_f) and the density of the submerged object (ρ_b) when analyzing Archimedes' principle. FluidInsight targets these learning bottlenecks directly; rather than presenting equations statically, the application operationalizes the PBL syntax by locking theoretical explanations until students navigate through real-world problem scenarios. However, the reason the N-gain did not reach the high effectiveness tier ($g \geq 0.7$) highlights distinct implementation challenges and learning difficulties. Observational field data showed that while students excelled at the qualitative, problem-driven phases, they experienced a sudden cognitive overload when transitioning to multi-variable algebraic problem-solving, which suggests that future iterations must integrate more gradual mathematical step-by-step scaffolding to aid students in translating physical phenomena into rigorous mathematical formulations.

The operational success of this conceptual scaffolding cannot be separated from the technological framework that powers the mobile medium itself. Therefore, the instructional efficacy of the FluidInsight application is heavily supported by the high level of operational implementation of the PBL syntax integrated into its technical features. Each PBL stage was executed through a tailored digital interface developed within the Kodular platform, which serves as a core novelty of this study. Unlike rigid, template-based authoring tools, the block-programming environment of Kodular allowed for the granular customization of interface parameters and interactive physics simulators. During the initial Orientation of Students to Problem stage, the application leverages the mobile architecture to embed high-definition multimedia elements, such as contextual videos of submarine mechanics and hydraulic lifts. This visual anchoring successfully stimulated students' intrinsic curiosity regarding hydrostatic pressure and Pascal's Law. This real-time response mechanism represents a primary pedagogical advantage over traditional printed media or passive e-books because, by actively testing hypotheses within the app, student errors are addressed immediately in the field, aligning closely with constructivist principles, which dictate that physics competency is maximized when students autonomously resolve authentic cognitive conflicts.

This active resolution of cognitive conflicts through a well-designed interface ultimately shapes how students perceive the overall utility and usability of the digital tool. In alignment with this technological integration, the direct correlation between application quality and improved learning outcomes is mathematically mirrored in the User Experience Questionnaire (UEQ) evaluation. FluidInsight achieved an "Excellent" benchmark rating in the hedonic quality dimensions of Attractiveness (2.036) and Stimulation (2.118), alongside "Good" ratings in pragmatic scales like Efficiency (1.842) and Perspicuity (1.765). A deeper analysis of these dimensions reveals critical psychological factors influencing student focus. The "Excellent" Stimulation score indicates that placing a functional, interactive physics laboratory inside the student's personal smartphone successfully eliminates the traditional disengagement associated with abstract sciences, effectively reframing physics from a tedious task into an immersive exploration. Concurrently, the high Attractiveness rating reflects the user interface (UI/UX) optimization executed in Kodular. By maintaining a clean visual hierarchy, minimizing navigational clutter, and color-coding fluid variables, the system heavily reduced the external cognitive load. Students did not waste restricted working memory capacity trying to figure out how to operate a frustrating software interface; instead, their mental faculties were fully liberated to focus on the underlying Problem-Based Learning tasks. Conversely, the lower relative score in the Novelty dimension (1.580) was an

intentional design compromise, as the engineering of FluidInsight deliberately prioritized cognitive clarity, programmatic stability, and clear content contextualization over superficial visual gimmicks or highly experimental layouts that could have triggered unnecessary split-attention effects.

While these psychometric and cognitive metrics paint a highly promising picture of the application's immediate impact, a comprehensive scientific evaluation requires an equally rigorous assessment of the framework's external constraints. Consequently, despite the positive empirical indicators, the claims regarding FluidInsight's effectiveness must be interpreted with strict methodological caution due to several critical limitations. Methodologically, the study's reliance on a One-Group Pretest-Posttest Design without an independent control group introduces distinct internal validity threats. Because there was no parallel control cohort to isolate external confounding variables, it is statistically challenging to assert a definitive, exclusive causal link between the mobile application and the posttest gains. External factors such as independent self-study outside school hours, peer-to-peer collaboration, or maturation effects over the course of the study could have partially influenced the observed learning gains. Furthermore, operational constraints limited the research scope; due to rigid institutional schedules and administrative timelines, the research was restricted to the 3D framework (Define, Design, Develop) of the 4D model, omitting the expansive Disseminate phase and limiting sample collection to a single school environment. Additionally, the evaluation parameters focused strictly on tracking cognitive learning outcomes, leaving the potential impact of the PBL application on students' psychomotor skills or affective behavioral shifts unexplored. Therefore, while this study provides a validated exploratory proof-of-concept for mobile constructivist learning under the *Kurikulum Merdeka* framework, future research must mitigate these validity threats by executing randomized quasi-experimental designs across diverse, multi-school cohorts to fully isolate the pedagogical impact of the FluidInsight platform.

4. CONCLUSION

In conclusion, the systematic development of the FluidInsight learning application through a modified 3D framework has yielded an instructional medium that is empirically proven to be valid, practical, and highly effective. The rigorous expert validation phase certified the application’s content alignment (91.11%) and media layout architecture (93.33%), while psychometric user evaluations placed its stimulation and attractiveness metrics firmly within the global database’s "Excellent" tier. Pedagogically, the operational integration of Problem-Based Learning (PBL) syntax into the mobile framework successfully transformed student learning outcomes, driving a significant conceptual shift that resulted in a moderate Normalized Gain (N-gain) score of 0.55 among eleventh-grade physics students. By shifting the instructional ecosystem from traditional teacher-centered rote learning to active, digital problem-solving, FluidInsight demonstrates that mobile learning can transcend beyond mere digitized textbooks to become an active cognitive scaffolding tool that effectively deciphers complex, abstract concepts within static fluid mechanics.

The broader educational implications of these findings offer vital insights and actionable pathways for classroom practice, particularly for secondary physics instructors navigating modern digital curricula. This study underscores that physics teachers can strategically leverage students' personal smartphones, frequently dismissed as classroom distractions, into productive, localized laboratory instruments by embedding constructivist software that delivers immediate, non-linear conceptual feedback. For practical classroom implementation, it is highly recommended that physics educators embed these mobile modules to stimulate cognitive conflict at the beginning of learning units through multimedia problem orientation, allowing students to independently experiment with variables before facing complex algebraic calculations. This approach directly supports the philosophy of student-centered learning environments advocated by the *Kurikulum Merdeka*, providing teachers with a scalable pedagogical catalyst to bridge the long-standing gap between theoretical environmental physics and concrete, everyday phenomena.

Beyond immediate classroom practices, this study delivers a significant technological contribution to the broader domain of mobile learning development and constructivist digital frameworks. By successfully operationalizing a complex instructional model like PBL within the Kodular builder environment, this research provides a scalable technical blueprint for creating lightweight, non-template-based Android applications that require zero high-level syntax

compilation yet maintain robust software stability. The operational model proves that visual block-programming platforms can be engineered to host real-time physics simulators and gated constructivist content, paving the way for educational technology developers to customize mobile software tailored to specific localized high school competencies. Consequently, this intersection of mobile architecture and constructivist syntax strengthens the framework of digital physics instruction, establishing that mobile learning achieves its highest pedagogical value when the software architecture itself strictly enforces active cognitive processing.

Despite these evident contributions, the exploratory nature of this research outlines essential directions for future feature enhancements and further empirical validation. To optimize the application's pedagogical scope, future iterations should integrate an adaptive, step-by-step mathematical tutorial feature to assist mid-tier students in translating qualitative physical phenomena into multi-variable algebraic formulas, thereby mitigating the observed cognitive overloads. Furthermore, because the present study's claims are bounded by a One-Group Pretest-Posttest Design within a single intact classroom section, future research must expand the empirical investigation into rigorous quasi-experimental or true experimental models. Subsequent studies should involve broader, multi-school student samples and incorporate randomized control groups to fully isolate external confounding variables, comprehensively trace the application's long-term impact on students' psychomotor or affective domains, and establish strong causal conclusions regarding mobile-assisted constructivist instruction.

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