Development and Feasibility of a PBL-Based Digital Science Comic for Static Fluid Learning

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Abstract

This study aimed to develop a Problem-Based Learning (PBL)-based digital science comic for teaching static fluid concepts and to examine its feasibility as a physics learning medium. The study employed a Research and Development (R&D) approach using the ADDIE model, which consists of analysis, design, development, implementation, and evaluation stages. The product was implemented with 26 Grade XI science students at SMAN 3 Majene. Feasibility was evaluated in terms of validity, practicality, and preliminary effectiveness. Validation by two physics education experts and one physics teacher indicated very high validity, with media and material validity scores of 97.95% and 97.99%, respectively. Practicality results showed that the comic was practical in the small-group trial (80.74%) and very practical in the large-group trial, based on student responses (91.37%) and teacher responses (92.22%). The effectiveness evaluation showed that 76.92% of students achieved the minimum mastery criterion after using the media. These findings indicate that the PBL-based digital science comic is valid, practical, and potentially effective for supporting student-centered physics learning on static fluid topics. However, the effectiveness evidence remains preliminary because the study did not employ a pretest-posttest design or a control group. Therefore, further studies are recommended to investigate the impact of the media on students' learning outcomes using more rigorous experimental designs.

Keywords: Digital Science Comic, Problem-Based Learning, Static Fluid, Physics Learning Media, ADDIE.

INTRODUCTION

Physics is a fundamental branch of natural science that plays an essential role in developing students' scientific understanding and reasoning skills. However, physics learning at the senior high school level often presents significant challenges due to the abstract nature of many concepts and the limited use of engaging instructional approaches (Hadi & Dwijananti 2015; Rahmi et al. 2019; Rerung, Sinon & Widyaningsih 2017). One topic that particularly illustrates this difficulty is static fluids, which involves concepts such as pressure distribution, density, and buoyant force. These phenomena cannot be directly observed, making it difficult for students to construct conceptual understanding when instruction relies primarily on textbooks and teacher-centered explanations.

Learning media therefore play a crucial role in supporting physics instruction by making abstract concepts more concrete and accessible. Well-designed learning media can increase students' motivation, foster active participation, and improve conceptual comprehension (Marisa et al. 2019; Achmad, Ghaida Prinisa 2022). Nevertheless, despite the rapid development of educational technology, many schools still depend on conventional teaching methods. Preliminary observations and interviews conducted at SMAN 3 Majene revealed that physics learning largely relied on blackboards and textbooks, while available digital resources such as smartphones, WiFi, and laptops were underutilized. Limited teacher experience in developing digital learning media further contributed to low student engagement and reduced interest in physics learning.

The characteristics of static fluid concepts indicate the need for learning media that are visual, contextual, and problem-oriented. Visual representations can help students understand invisible phenomena, narrative contexts can connect scientific concepts with everyday experiences, and problem situations can stimulate active inquiry and reasoning. One learning media that possesses these characteristics is science comics. Science comics combine images, narratives, and dialogue to facilitate cognitive and emotional engagement with scientific content (Daryanto 2016; Lin et al. 2015; Matuk et al. 2021). Previous studies have demonstrated that science comics can enhance students' interest, conceptual understanding, and retention of scientific information by presenting complex material in a more intuitive and enjoyable manner (Friesen, Van Stan & Elleuche 2018; Canuto et al. 2024; Ghofur 2022). Moreover, digital comics accessible through smartphones provide greater flexibility and accessibility for students who are familiar with digital environments (Savitri, Karim and Hasbullah, 2020; Tania, Jumadi and Tolino, 2020; Iwung and Nugraha, 2022)

However, many existing science comics mainly function as explanatory media that emphasize content presentation rather than engaging students in inquiry and problem-solving activities. Students often act as passive readers who receive information without opportunities to analyze problems or construct solutions independently (Friesen, Van Stan & Elleuche 2018; Ghofur 2022; Canuto et al. 2024). Therefore, science comics need to be integrated with an instructional approach that promotes active learning and higher-order thinking.

Problem-Based Learning (PBL) provides a suitable pedagogical framework because it encourages students to learn through contextual problems and systematic problem-solving processes (Rerung, Sinon & Widyaningsih 2017; Israel 2022; Wajdi et al. 2022). The stages of PBL, including problem orientation, investigation, solution development, and reflection, can be incorporated into comic narratives through contextual scenarios, guiding questions, and reflective activities. In this way, digital comic can function not only as storytelling media but also as structured learning environments that support students' inquiry and reasoning processes.

Several studies have reported the feasibility of combining comic with the PBL approach in science and mathematics learning (Rahmah, Mailizar & Yusrizal 2020; Pertiwi et al. 2021). However, these studies generally emphasize feasibility or learning outcomes without explicitly describing how PBL stages are systematically embedded within the comic narrative and learning activities. Furthermore, studies specifically developing PBL-based digital science comic for static fluid topics in senior high school physics remain limited.

Therefore, this study addresses these gaps by developing a digital science comic that explicitly integrates PBL stages into the storyline, learning tasks, and reflective components. The novelty of this study lies in the systematic mapping of PBL syntax into the comic structure to support students' problem-solving processes in learning static fluids. Accordingly, this study aims to develop a PBL-based digital science comic using the ADDIE model and to evaluate its feasibility in terms of validity, practicality, and effectiveness.

METHOD

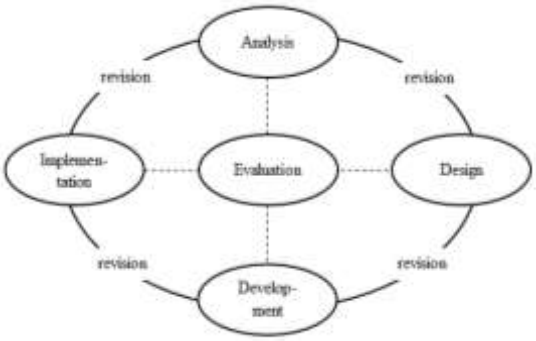


FIGURE 1. Stages of Research and Development Using the ADDIE Model

This study employs the Research and Development (R&D) method. R&D is a research approach used to produce and test the effectiveness of a specific product (Sugiyono, 2020). In this study, the product developed is a PBL-based digital science comic for static fluid material in physics. The

development process follows the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation, as illustrated in Figure 1.

The First Stage: Analysis. At this stage, various foundational aspects are analyzed to guide the product's design and development. It includes a) needs analysis: identifies fundamental learning problems and instructional needs, b) students' analysis: determines the characteristics of students, including their learning styles and technology access, c) learning media analysis: reviews previous studies on engaging and effective learning media, d) curriculum analysis: analyzes the relevant curriculum and identifies physics content at SMAN 3 Majene suitable for delivery through digital comic based on PBL.

Second stage: Design. In this phase, the initial concept of the digital science comic is formulated. This includes detailed planning of content structure, visual elements, narrative flow, and integration of PBL syntax (Batubara, 2020).

Third Stage: Development. This stage involves the production and revision of the digital comic. Activities include a) development of digital science comic: creation of the comic media based on the design, b) preparation of research instruments: development of tools for data collection such as validation sheets, student and teacher response questionnaires, and learning outcome tests, c) expert validation: the product and research instruments is reviewed by experts (validators) to determine the validity and provide feedback for improvement. The expert validation process involved three validators consisting of two university lecturers in physics education with expertise in physics instruction and learning media development, and one experienced senior high school physics teacher with more than five years of teaching experience. To determine the validity, expert validation scores are calculated using equation (1).

$$Validity = \frac{\sum Expert\ Score}{\sum Maximum\ Score} \times 100\% \quad (1)$$

The validity category is determined based on table 1.

TABLE 1. Criteria for Validity of the Science Comic

Category	Percentage (%)
Very Valid	81% - 100%
Valid	61% - 80%
Fairly Valid	41% - 60%
Invalid	21% - 40%
Very Invalid	0% - 20%

(Krismadinata, Anwar & Akbar 2021)

The aspects and indicators used to assess the validity of the media are presented in table 2, while the aspects and indicators used to assess the validity of the material are presented in table 3.

TABLE 2. Aspects and Indicators for Media Validity Assessment of the Science Comic

No.	Aspect	Indicators
1	Comic identity	The comic includes a title, target grade level, author name, and the logo of the producing institution.
		The placement of the title, target grade level, author name, and institutional logo is appropriate and well-organized.
2	Panels and gutters	The layout of panels is balanced and well-organized.
		Margins are consistent.
		The width of the gutters is consistent throughout the comic.
3	Illustrative images	The images clarify the messages conveyed by the comic characters.
		The image size is appropriate.
		The images are free from content containing pornographic elements.
4	Speech balloons and narration	The shape of speech balloons matches the content of the dialogue.
		The sequence of speech balloons follows a standard reading direction (left to right, top to bottom).
		Dialogue text is easy to read and does not use numbering.
		The storyline is easy to understand, engaging, and follow the PBL syntax.

		Dialogue text uses casual, concise, and communicative language and is free from typographical errors. Narration messages are easy to understand, and the background colour is consistent with the speech balloon background. Font type and size are appropriate and readable.
5	Follow-up activities	The comic includes follow-up activities that encourage students to learn actively, such as completing assignments and answering quizzes. Follow-up instructions are clear and easy to understand.
6	Ease of use	The science comic media is practical and easy to use. Overall, the science comic has an attractive visual appearance.

(Batubara, 2020)

TABLE 3. Aspects and Indicators for Material Validity Assessment of the Science Comic

No.	Aspect	Indicators
1	Content	Clarity of the topic presented in the media. Alignment of the material content with Core Competencies and Basic Competencies (KI/KD). Alignment of the content with the learning objectives. Conceptual accuracy of the material. Appropriateness of the use of images and illustrations. Inclusion of real-world problems relevant to students' daily experiences. The material enriches students' knowledge and understanding. Encourages students' curiosity. Free from elements of SARA (ethnicity, religion, race, and intergroup issues) and pornography.
2	Presentation	Text is clearly readable. The presentation of the material is engaging and logically structured. The material is easy to understand. The presentation of the material is systematic and well-sequenced. The material is accompanied by example problems. Practice questions are provided along with feedback.
3	Language	Use of communicative language. Simplicity of sentence structure. Consistency in the use of terminology.

(Angga, Sudarma and Suartama, 2020)

Fourth Stage: Implementation: this phase tests the learning media with actual users in two stages a) small group trials: the initial version of the digital science comic was tested with 6 Grade XI science students at SMAN 3 Majene who were selected to represent students with high, medium, and low academic achievement levels. The purpose of this stage was to identify usability issues, obtain students' responses, and gather suggestions for improving the media. Feedback obtained during this trial was used to revise the comic before the larger implementation, and b) large group trials: the revised media is tested in a broader setting with 26 Grade XI science students at SMAN 3 Majene. The implementation was conducted during 4 instructional meetings**,** with each meeting lasting approximately 90 minutes**,** covering the static fluid topics included in the comic. This study used a one-shot case study design (Sugiyono, 2020), in which a single group of students was exposed to the developed PBL-based digital science comic and evaluated after implementation. This design was selected because the research focused on developing and examining the feasibility of a learning media within an R&D framework using the ADDIE model, rather than comparing learning outcomes across groups. One-shot case studies are commonly applied in development research to obtain initial evidence of practicality and functional effectiveness in real classroom contexts while minimizing disruption to regular instruction (Sugiyono, 2019; Rahmah, Mailizar and Yusrizal, 2020). However, the absence of a control group and pretest data limits causal interpretation of learning outcomes; therefore, the effectiveness results should be viewed as preliminary, and future studies are recommended to employ quasi-experimental or experimental designs for stronger validation.

At this stage, the practicality and effectiveness of the PBL-based digital science comic were evaluated following its classroom implementation.

Practicality was measured using student and teacher response questionnaires. Prior to implementation, both questionnaires were validated by expert validators to ensure the quality and appropriateness of the instruments. The validation covered three aspects, namely format, content, and language. The student response questionnaire obtained a validity score of 91.90%, while the teacher response questionnaire achieved a validity score of 92.59%. Both instruments were categorized as very valid, indicating that they were appropriate for measuring the practicality of the developed digital science comic. Each questionnaires consisting of 11 items and employed a five-point Likert scale. The response scale ranged from 1 to 5, where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. The obtained scores were analyzed using equation (2) to determine the level of practicality of the developed learning media.

$$Practicality = \frac{\sum User\ Score}{\sum Maximum\ Score} \times 100\% \quad (2)$$

The levels of practicality are categorized in table 4.

TABLE 4. Practical for Criteria Science Comic

Category	Percentage (%)
Very Practical	81% - 100%
Practical	61% - 80%
Fairly Practical	41% - 60%
Impractical	21% - 40%
Very Impractical	0% - 20%

(Krismadinata, Anwar & Akbar 2021)

The aspects and indicators used to assess the practicality of the digital science comic are presented in table 5.

TABLE 5. Aspects and Indicators for Practicality Assessment

No.	Aspect	Indicators
1	Ease of Use	The digital science comic is easy to use. The language used in the digital science comic is easy to understand.
2	Usefulness	The use of the digital science comic in physics learning is not boring. The material presented in the comic helps students remember and understand physics concepts. The digital science comic encourages students to be more active during physics learning. The digital science comic increases students' reading interest. The digital science comic increases students' interest in learning physics. The presentation of the material motivates students to learn physics.
3	Visual Appearance	The appearance of the digital science comic is attractive. The text in the digital science comic is clearly readable. The illustrations/images are visually appealing.

(Nella and Sylvia, 2020)

Furthermore, the PBL-based digital science comic was considered effective if students successfully completed the learning process using the developed product. Based on observations and interviews with the physics teacher at SMAN 3 Majene, students were considered to have achieved mastery if they reached the Minimum Mastery Criterion (KKM) of 75. The learning outcomes test used to evaluate students' understanding of static fluid concepts (20 multiple-choice items) was validated by expert validators prior to implementation. The validation process assessed the appropriateness of the test items in terms of content, construction, and language to ensure their alignment with the learning objectives and curriculum indicators. The learning outcomes test obtained a validity score of 87.96% and was categorized as very valid, indicating that the instrument was appropriate for assessing students' understanding of static fluid concepts.

To determine the effectiveness of the developed science comic on students' learning outcomes in static fluid material, the learning outcomes test results were analyzed using equation (3) (Rachmawati and Sumargiyani, 2021).

$$Effectiveness = \frac{\sum Students\ reached\ KKM}{\sum students} \times 100\% \quad (3)$$

The criteria for effectiveness are shown in table 6.

TABLE 6. Effective Criteria of Science Comic

Category	Percentage (%)
Very Good	80% - 100%
Good	60% - 79%
Fair	40% - 59%
Poor	20% - 39%
Very Poor	0% - 19%

(Rachmawati and Sumargiyani, 2021)

Fifth Stage: Evaluation. Evaluation is conducted at each stage of the ADDIE model to ensure the quality and effectiveness of the product. This includes both formative and summative evaluations.

RESULTS AND DISCUSSION

The development of PBL-based digital science comic as a physics learning media at SMAN 3 Majene employed the ADDIE development model. The detailed results at each stage are as follows:

Analysis

This stage was conducted through four steps:

Needs Analysis

Observations and interviews with physics teachers at SMAN 3 Majene revealed that teachers had not been using engaging learning media in classroom activities. Most educators relied solely on blackboards and textbooks, without utilizing the rapid technological advancements available for teaching, particularly in physics. Teachers also encountered difficulties in preparing technology-based learning media due to limited technical skills. However, supporting facilities such as smartphones, WIFI, laptops, and computers were already available to both teachers and students.

The teaching process remained teacher-centered, and student interest in physics was low, resulting in minimal student engagement and low comprehension, which ultimately impacted learning outcomes. This lack of interest could be attributed to uninspiring learning activities and the limited use of media that fosters deeper engagement. Therefore, students require engaging learning media that can spark interest and stimulate active participation.

Media Analysis

Media analysis examined the availability of learning facilities and technology in the school environment. The analysis showed that most students had access to smartphones and internet connectivity, but these resources were rarely utilized for physics learning. Literature review of studies by (Pertiwi et al. 2021; Susiaty, Firdaus & Oktaviana 2024; Rahmah, Mailizar & Yusrizal 2020; Rahayu & Kuswanto 2020; Damopolii & Rahman 2019; Kaur 2019; Matuk et al. 2021; Fatimah & Fatonah 2023; Maghfiroh, Kuswanto & Susetyo 2020; Canuto et al. 2024) found that comics can effectively capture students' attention and foster interest in learning. Therefore, a digital comic format accessible via mobile devices was considered suitable to support learning flexibility, accessibility, and enhance student interest in learning.

Student Analysis

Student analysis focused on identifying students' learning characteristics, preferences, and difficulties in learning physics. Classroom observations and interviews revealed that students experienced difficulties understanding abstract static fluid concepts and showed low engagement during conventional instruction. In addition, previous studies have shown that students tend to enjoy visual and narrative-based learning materials such as comic, which can increase learning interest and motivation (Lin et al. 2015; Matuk et al. 2021; Canuto et al. 2024; Pertiwi et al. 2021). These findings support the selection of comic as an appropriate learning media for senior high school physics.

Curriculum Analysis

Curriculum analysis was conducted to ensure that the development of the PBL-based digital science comic aligns with the competency standards and learning objectives of senior high school physics. This analysis focused on identifying the relevant core competencies and basic competencies that require students to understand static fluid concepts, apply physical laws, and solve contextual problems related to everyday phenomena. In the curriculum, static fluid material emphasizes students' ability to explain physical principles, analysed phenomena involving fluids at rest, and apply these principles to real-life situations. Based on the curriculum analysis, a material analysis was conducted to determine the scope, depth, and contextualization of static fluid content to be embedded in the digital comic. The selected materials included pressure, hydrostatic pressure, Pascal's law, Archimedes' principle, surface tension, and capillarity, as these concepts are core components of static fluid competencies and are frequently encountered in students' daily lives. The concept of pressure was introduced through the context of a nail and a hammer, enabling students to analyze the relationship between force, contact area, and pressure. Hydrostatic pressure was contextualized through swimming and diving activities, which helped students understand how pressure increases with depth.

Furthermore, Pascal's law was presented using the working principle of a hydraulic car wash system, allowing students to explore pressure transmission in confined fluids. Archimedes' principle was illustrated through the phenomenon of floating ships, guiding students to examine the relationship between buoyant force, fluid density, and object volume. The concept of surface tension was introduced using the phenomenon of a mosquito standing on the surface of water, encouraging students to analysed intermolecular forces in liquids. Finally, capillarity was explained through the process of oil rising along the wick of an oil lamp, enabling students to explore the interaction between adhesive and cohesive forces in fluids.

All materials were organized progressively from simple to complex concepts and embedded within contextual problem scenarios in the comic storyline. Each topic was designed to guide students through the stages of Problem-Based Learning, starting from problem orientation, followed by problem analysis, information exploration, solution development, and reflection. This integration ensured that the comic content was curriculum-aligned, conceptually accurate, and pedagogically structured, supporting the achievement of learning competencies in static fluid material.

Design

The design stage is a continuation of the analysis stage. At this stage, the product concept was designed by translating ideas into a detailed formulation that describes the PBL-based digital science comic. The media design was structured in the form of a storyboard, which outlines the sequence of content, storyline, visual elements, and learning activities. The materials included in the storyboard were compiled from various sources, such as textbooks, learning modules, and online resources. The storyboard functioned as a development guideline to facilitate the systematic creation of the digital science comic. Figure 2 presents an excerpt of the storyboard (originally written in Indonesian) used as a design guideline for developing the PBL-based digital science comic.

FIGURE 2. An excerpt of the storyboard of the PBL-based digital science comic developed in this study.

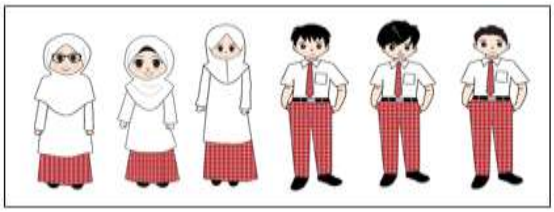


FIGURE 3. Characters in comic

At this stage, character design was also developed. Initially, the comic characters were adapted from Canva using standard Indonesian senior high school uniforms (white and gray). However, an evaluation conducted during this stage indicated the need to create characters that were more unique and relevant to the research context. Consequently, the comic characters were independently illustrated by the researcher using the IbisPaint X application. The school uniforms worn by the characters were redesigned to incorporate *lipa' sa'be*, a traditional Mandar silk sarong, to reflect local cultural identity. Several examples of the developed characters are presented in figure 3.

Development

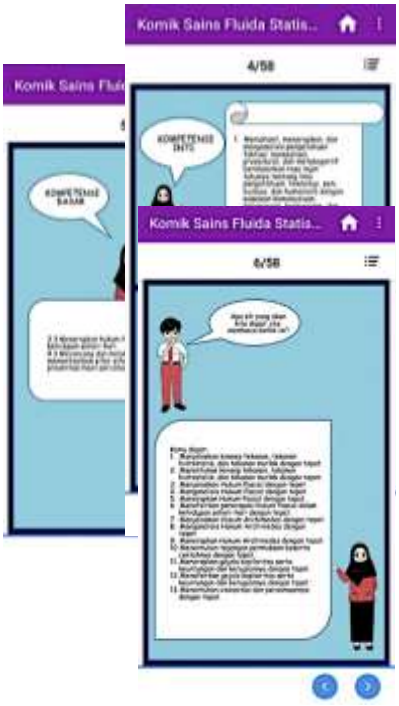
Comic Development

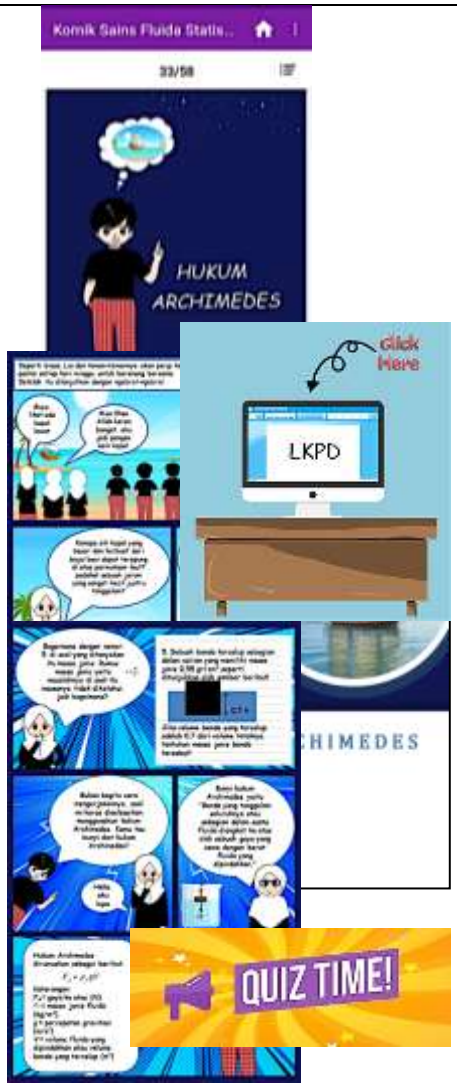
At this stage, a PBL-based digital science comic was developed using Microsoft PowerPoint by referring to the storyboard produced during the design stage. The PowerPoint file was then converted into HTML format using the iSpring Suite 10 add-in. Subsequently, the HTML output was transformed into an Android application that can be operated on smartphones using Website 2 APK Builder. This process enabled the comic to be accessed flexibly through mobile devices, in line with students' digital learning habits.

The developed digital science comic was intentionally designed based on the PBL approach, as PBL encourages active student engagement throughout the learning process (Halim, Suriana and Mursal, 2017; Nulhakim, Setiawan and Saefullah, 2020). According to (Rerung, Sinon & Widyaningsih 2017) PBL is an innovative learning model that creates active learning conditions for students. The PBL syntax was explicitly embedded in the structure of the digital science comic. The storyline was presented in a contextual manner and accompanied by problem situations that students were required to solve, which represents a key characteristic of PBL (Pertiwi et al. 2021; Rahmah, Mailizar & Yusrizal 2020).

After undergoing several evaluation cycles, improvements were made to the digital science comic, particularly in refining the clarity of text within speech bubbles, reorganizing the sequence of problem presentation to better reflect the PBL syntax, and adjusting illustrative images to ensure consistency with the learning material. These revisions resulted in a more coherent and pedagogically aligned product. The finalized digital science comic consists of several key features, which are described in table 7.

TABLE 7. The digital science comic key features.

No	Features	Science Comic Display	Description
1	Cover, Usage Guide, and Character Introduction.		• The cover of the digital science comic contains the comic title, the target grade level, the name of the developer, and the logo of the developing institution. • The usage guide provides an introduction to the features available in the digital science comic. This section is intended to help users understand and easily navigate the features included in the comic, thereby supporting effective use during the learning process. • The character introduction section is designed to familiarize readers with the characters appearing in the digital science comic.
2	The core competencies, basic competencies, and learning objectives.		The core competencies and basic competencies used in the digital science comic were derived from Regulation of the Ministry of Education and Culture Number 37 of 2018. The learning objectives presented in the science comic were formulated based on the Indicators of Competency Achievement that had been established.

3	The Content		The content of the digital science comic was designed by integrating the PBL syntax through dialogues and interactions among the characters in each static fluid subtopic. At the beginning of each material section, the characters are presented with contextual problems related to static fluid phenomena encountered in daily life, such as pressure, hydrostatic pressure, Pascal's law, Archimedes' principle, surface tension, and capillarity. The character dialogues guide students to identify problems, formulate questions, and propose initial solutions, representing the problem orientation and problem formulation stages of PBL. Subsequently, the storyline and conversations direct students to collect and analyze relevant information through conceptual explanations, visual illustrations, and guided discussions among the characters. To ensure the systematic implementation of PBL, each subtopic is accompanied by Student Worksheets (LKPD) containing problem-solving activities, data analysis tasks, and conclusion drawing. At the end of each subtopic, a quiz is provided to measure students' learning outcomes and to reinforce reflection on the problem-solving process. Through this design, the comic functions not only as a visual learning media but also as an active learning tool that supports the full implementation of PBL in teaching static fluid material.

Drafting of Research Instruments

The instruments developed in this study included expert validation sheets to assess the media and content validity of the digital science comic based on the aspects presented in Tables 2 and 3. Practicality was evaluated using teacher and student response questionnaires developed according to the aspects outlined in Table 5. The effectiveness of the developed comic was measured using a learning outcomes test, which was constructed based on the cognitive domain of Bloom's taxonomy to evaluate students' learning outcomes. All instruments were also validated by experts, with revisions conducted to refine the wording of the response questionnaire items, adjust the learning outcomes test items to align with the intended cognitive levels, and improve the scoring rubrics. Reliability testing for instruments in this research was not conducted due to the limited sample size.

Expert Validation

Validation of the PBL-based digital science comic was conducted by two lecturers from the Physics Education Study Program at the University of West Sulawesi and one physics teacher from SMAN 1 Majene. The objective of this validation was to evaluate the quality of the comic in terms of both media design and content accuracy.

Media and material expert validation for each aspect of the assessment is presented in Table 8 and 9 below.

TABLE 8. Results of Science Comic Media Validation by the Three Validators for Each Aspect

No.	Aspect	Average (%)	Category
1	Comic Identity	95.83	Very Valid
2	Panels and Gutters	100.00	Very Valid
3	Illustrative Images	97.22	Very Valid
4	Speech Ballons and Narration	98.81	Very Valid
5	Follow-Up Activities	100.00	Very Valid
6	Ease of use	95.83	Very Valid
	Average	97.95	Very Valid

TABLE 9. Results of Science Comic Material Validation by the Three Validators for Each Aspect

No.	Aspect	Average (%)	Category
1	Content	98.15	Very Valid
2	Presentation	98.61	Very Valid
3	Language	97.22	Very Valid
	Average	97.99	Very Valid

Based on Tables 8 and 9, the average scores for media and material validation by the three validators were 97.95% and 97.99%, respectively, both categorized as very valid. These results indicate that the developed PBL-based digital science comic meets high standards in terms of both media quality and material quality. The high validity score not only confirms the technical feasibility of the developed digital science comic but also strengthens the novel contribution of this study, namely the systematic integration of Problem-Based Learning (PBL) syntax within a digital comic format for static fluid concepts. Unlike conventional science comics that primarily function as explanatory or illustrative media, the validated comic embeds problem scenarios, guided inquiry prompts, follow-up activities, and assessments directly within the narrative structure. The positive validation results indicate that this integration was implemented coherently, without compromising visual quality, readability, or instructional flow. Furthermore, the alignment between visual design, dialogue progression, and PBL stages demonstrates that the comic is not merely a digital reading material but a usable instructional media that actively supports student-centered learning processes. These findings highlight the study's contribution to physics education research by providing empirical evidence that digital comic can be purposefully designed not only to increase students' interest but also to operationalize inquiry-oriented learning models such as PBL, particularly for abstract physics topics like static fluids at the senior high school level.

Implementation

The implementation stage aimed to examine the practicality and effectiveness of the developed PBL-based digital science comic in an authentic classroom setting. At this stage, the validated learning media was implemented in physics instruction on static fluid material for Grade XI science students at SMAN 3 Majene through small-group and large-group trials. The small-group trial was conducted to obtain initial feedback related to usability, clarity of content, and technical functionality of the media, while the large-group trial was carried out to evaluate the practicality and effectiveness of the comic in a real classroom environment (Nella and Sylvia, 2020). During implementation, the digital science comic was integrated into the learning process in accordance with the Problem-Based Learning (PBL) syntax, enabling students to engage with contextual problem scenarios, guided inquiry activities, LKPD-based tasks, and quizzes embedded within the comic (Fatimah & Fatonah 2023; Rerung, Sinon & Widyaningsih 2017). This stage provided empirical data from student and teacher responses as well as students' learning outcomes to determine the feasibility of the developed media under actual learning conditions.

Small Group Trials

The results of student responses for each aspect of the assessment in small group trials are presented in table 10 below.

TABLE 10. Result of student response on the small group trials for each aspect

No.	Aspect	Average (%)	Category
1	Ease of use	80.00%	Practical
2	Benefit	81.10%	Very Practical
3	Visual Appearance	81.13%	Very Practical
	Average	80.74%	Practical

Based on Table 10, the average student response score for each aspect of using the science comic is 80.74%, which falls into the "Practical" category. In the small group trial, students did not report any difficulties or provide suggestions regarding access to the science comic. Therefore, the science comic was deemed ready for implementation in a large group trial.

Large Group Trials

The results of student responses for each aspect of the assessment are presented in table 11 below.

TABLE 11. Results of student response on the large group trials for each aspect

No.	Aspect	Average (%)	Category
1	Ease of use	90.38	Very Practical
2	Benefit	90.90	Very Practical
3	Visual Appearance	92.82	Very Practical
	Average	91.37	Very Practical

In addition to the students completing the questionnaire, the teacher also participated in the large group trial by completing a response questionnaire. The results of the teacher's responses for each aspect of the assessment are presented in table 12 below.

TABLE 12. Results of Teacher Responses in Large Group Trials for Each Aspect on the Teacher Response Questionnaire

No.	Aspect	Average (%)	Category
1	Ease of use	100.0	Very Practical
2	Benefit	90.00	Very Practical
3	Visual Appearance	86.67	Very Practical
	Average	92.22	Very Practical

Based on Tables 11 and 12**,** the average responses from both students and the teacher toward the use of the PBL-based digital science comic reached 91.37% and 92.22**,** placing it in the very practical category. This finding indicates that the developed comic is perceived as easy to use, engaging, and beneficial in supporting the learning process. From the students' perspective, the high practicality score reflects strong acceptance of the comic's visual presentation, narrative flow, and interactive features, which helped maintain interest and encouraged active participation during learning activities. Meanwhile, the teacher's positive response suggests that the comic is practical in terms of instructional clarity, alignment with learning objectives, and ease of classroom integration without requiring complex technical skills. The consistency between student and teacher evaluations demonstrates that the comic is not only appealing to learners but also feasible for instructional use. These results reinforce the study's contribution by showing that embedding PBL stages within a digital comic format can produce a learning media that is both pedagogically meaningful and practically implementable in real classroom contexts.

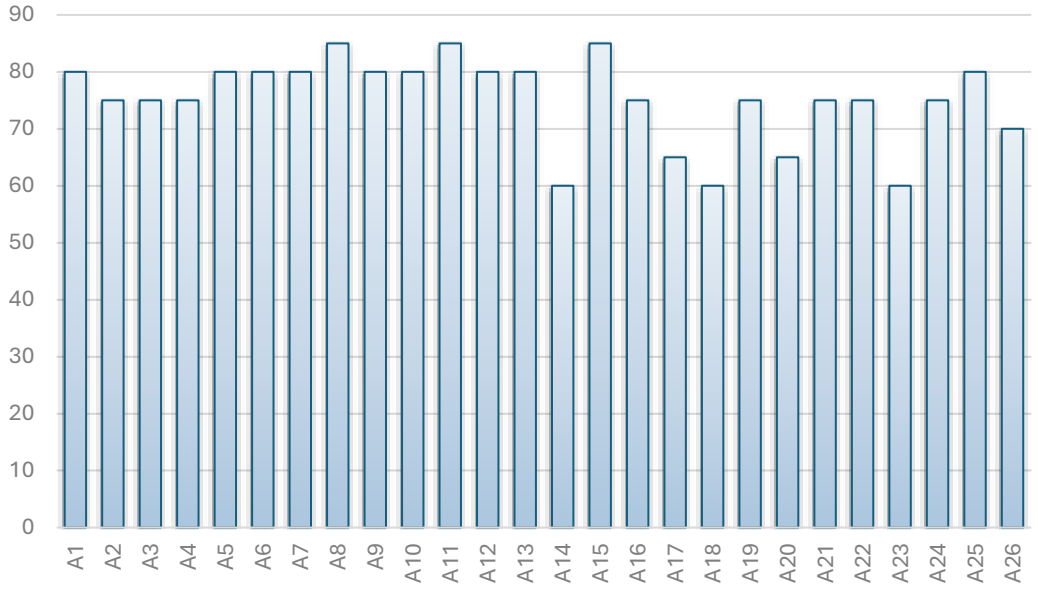


FIGURE 4. Learning Outcome's Results.

During the large group trial, students were not only asked to complete a response questionnaire but also to take a learning outcomes test. Based on figure 4, out of 26 participants, 20 students achieved scores above the Minimum Mastery Criterion (KKM) of 75, while 6 students did not achieve the criterion. The analysis showed that 76.92% of the students achieved learning mastery. This result indicates that the students' learning outcomes meet the criteria for effectiveness.

TABLE 13. The Descriptive Analysis of Students' Learning Outcome Scores

Statistic	Value
Number of Students	26
Mean	75.40
Minimum Score	60
Maximum Score	85
Standard Deviation	7.47

The descriptive analysis of students' scores based on table 13, revealed a mean score of 75.40, with a minimum score of 60, a maximum score of 85, and a standard deviation of 7.47. These results suggest that most students were able to achieve the expected level of understanding of static fluid concepts after learning with the PBL-based digital science comic. The relatively small standard deviation indicates that students' achievement scores were not widely dispersed, suggesting a relatively consistent learning outcome among students.

These findings are consistent with previous studies reporting the positive effects of comic-based and digital learning media. (Savitri, Karim and Hasbullah, 2020) developed Android-based learning media that fulfilled validity and practicality criteria, while (Hadi and Dwijananti, 2015) reported improvements in students' learning outcomes through Android-based physics comics on radioactivity topics. Similar findings have also been reported by (Achmad, Ghaida Prinisa, 2022; Budi Cahyono *et al.*, 2023) indicating that comic-based learning media can effectively attract students' attention and facilitate learning.

The effectiveness of the developed digital science comic may be explained by several specific design features. First, visual illustrations and contextual narratives helped students visualize abstract static fluid concepts, such as hydrostatic pressure and buoyant force, which are difficult to observe directly. Second, the integration of PBL stages into the comic structure encouraged students to engage actively with the learning content. Contextual problems presented at the beginning of each section stimulated students to identify problems, while worksheets and guiding questions embedded within the

comic dialogues supported investigation and concept exploration. Quizzes and reflective tasks provided opportunities for students to evaluate their understanding and reflect on their reasoning processes. These pedagogical features transformed the comic from a passive reading media into an active learning environment. The combination of visual representations, narratives, and problem-solving activities may explain why most students achieved the minimum mastery criterion. The mean score of 75.38 and the mastery level of 76.92% indicate that the developed media has the potential to support students' understanding of static fluid concepts.

Previous studies have shown that comics can stimulate students' interest in learning (Damopolii & Rahman 2019; Kaur 2019; Canuto et al. 2024), improve students' learning outcomes (Molina & Cadorna 2025), and enhance critical thinking skills (Maghfiroh and Kuswanto, 2022). Furthermore, Problem-Based Learning promotes active participation and engagement through real-life problem situations. Research by (Rerung, Sinon & Widyaningsih 2017) shows that PBL can improve students' learning outcomes in physics. Therefore, the positive findings of this study may result from the complementary roles of comic-based visualization and the problem-solving orientation provided by PBL.

The implementation of the five ADDIE stages, namely analysis, design, development, implementation, and evaluation, resulted in a digital science comic that fulfilled the criteria of validity, practicality, and effectiveness. Therefore, the developed PBL-based digital science comic can be considered a feasible alternative learning media for senior high school physics instruction.

Despite these positive findings, this study has several limitations. The implementation involved a relatively small sample size and was conducted in a single school, which may limit the generalizability of the results. In addition, the duration of the implementation was relatively short and employed a one-shot case study design without a comparison group, restricting the ability to draw causal conclusions regarding learning effectiveness. Future studies are therefore recommended to involve larger and more diverse samples, multiple school contexts, longer implementation periods, and experimental or quasi-experimental designs to further examine the impact of PBL-based digital science comic on students' learning outcomes and higher-order thinking skills.

CONCLUSION

In conclusion, the PBL-based digital science comic developed in this study fulfilled the criteria of validity, practicality, and effectiveness, indicating that it is feasible for use as an alternative learning media for teaching static fluid concepts in senior high school. The effectiveness findings provide preliminary evidence that the developed media can support students' understanding of static fluid concepts. The integration of PBL stages into the digital comic structure offers practical implications for physics teachers by providing a contextual and student-centered learning media that facilitates problem solving and active engagement in the classroom. However, the effectiveness findings should be interpreted cautiously because the study employed a one-shot case study design without a control group or pretest. Future studies are recommended to involve larger samples and experimental or quasi-experimental designs to provide stronger evidence regarding the effectiveness of PBL-based digital science comic in physics learning.

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