

PAPER

Augmented Reality with the Cognitive Conflict Model: What Is Effective for Improving Students' Scientific Literacy of Dynamic Fluid Material?

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ABSTRACT

This study aimed to develop an augmented reality (AR) application by integrating the cognitive conflict-based learning (CCBL) model to enhance students' scientific literacy in a dynamic fluid material. The study followed a design or development framework utilizing the Plomp model stages, including design, validity, practicality, and effectiveness tests. In the effectiveness test phase, a quasi-experimental design was applied with control and experimental groups. The control group consisted of 36 students who learned through traditional methods, while the experimental group included 36 students who learned using AR. The application design characteristics incorporated the stages of the CCBL model, presenting AR at each stage. The validity test of the AR application yielded a score of 0.95, which was categorized as valid. The practicality test scored 94% in the one-to-one stage and 95.7% in the small group stage, categorized as practical. The effectiveness test demonstrated that AR-based learning was superior to traditional learning methods in improving students' scientific literacy regarding dynamic fluid material. Overall, the AR application designed with the characteristics of the CCBL model stages was validated, practical, and effective, representing an innovative solution for improving students' scientific literacy in physics education.

KEYWORDS

augmented reality (AR), dynamic fluid, scientific literacy

1 INTRODUCTION

Learning in the 4.0 industrial revolution era towards society 5.0 has significantly improved in supporting enhancing students' scientific literacy. The primary focus of this learning approach is to strengthen students' abilities in science and technology through investigation and discovery processes, which are key to improving scientific literacy [1], [2]. With a solid mastery of scientific literacy, students are expected to understand and interpret scientific phenomena, think critically, and adapt to the

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demands of the technological advancements [3]. This approach also emphasizes the importance of collaboration and communication in interactive learning environments, allowing students to share ideas, sharpen their understanding of science, and develop relevant skills to face future challenges [4].

The availability of supporting infrastructure is crucial in achieving optimal scientific literacy capabilities. In physics education, for example, the training process in investigation and discovery skills must be a top priority. However, many physics materials, particularly those related to abstract concepts such as fluids [5], face limitations in teaching media. The lack of appropriate experimental equipment and simulation support media to explain physical phenomena poses a serious problem in the learning process. These limitations hinder the development of students' scientific literacy abilities [6]. The 2023 PISA results reveal that Indonesian students' scientific literacy abilities are categorized as low, reflecting their difficulties in explaining phenomena, interpreting data, and conducting investigations [7].

These challenges create a gap in physics education in supporting the mastery of scientific literacy. One solution to address these limitations is to integrate interactive technology into learning. The technology presented to support physics education, especially regarding fluid materials, must be capable of aiding in explaining concepts, interpreting data, and supporting scientific investigations to enhance student capabilities. Previous technologies implemented in learning were dominated by images and videos with two-dimensional visualization limitations, often resulting in incomplete information [8], [9], [10]. The advent of 3D visualization technology offers better support in addressing the shortcomings of earlier media. One such technology is augmented reality (AR) [11], [12]. AR provides visualization and simulation support for 3D objects within a real-world environment. This AR capability offers better support in explaining physics materials. AR enhances scientific investigations through simulations, facilitating inquiry-oriented learning [13].

The benefits of AR align with inquiry-oriented learning models, such as the cognitive conflict-based learning (CCBL) model, which enhances scientific literacy. The CCBL model involves stages consisting of the activation of preconceptions and misconceptions, presentation of cognitive conflicts, discovery of concepts and relationships, and reflection [14], [15]. AR technology supports these stages by allowing students to visualize phenomena in 3D, helping them solve problems and address misunderstandings. The combination of simulations and virtual laboratories strengthens students' scientific literacy by encouraging deeper understanding and inquiry, particularly in abstract topics such as fluid dynamics. Thus, this study aims to develop an AR application by integrating the CCBL model to enhance students' scientific literacy abilities in dynamic fluid material.

2 METHODS

2.1 Research design

The study adopted the Plomp development model, which proved effective and suitable for creating educational products. With a systematic approach, this model included stages such as preliminary research, design or development, and assessment phase [16]. Each stage was designed to ensure that the resulting product was valid, practical, and effective in supporting the learning process. With clear and straightforward steps, the Plomp model facilitated the development of high-quality educational products that met the needs. The complete stages of this study can be seen in Figure 1.

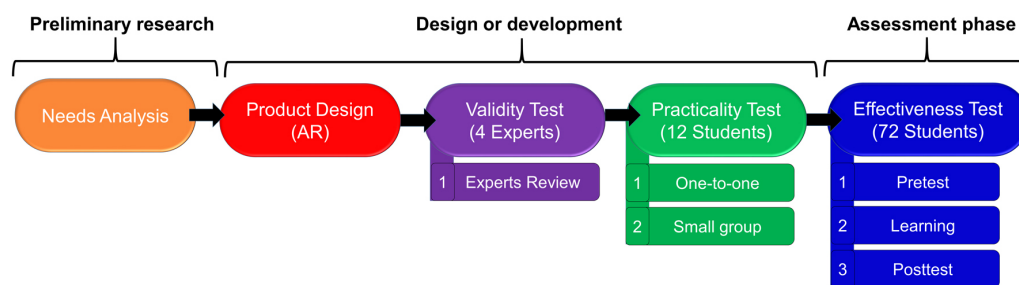


Fig. 1. Plomp model

Figure 1 displays the stages of product development, from needs analysis to effectiveness tests. The needs analysis stage aimed to identify learning gaps, determine student needs, and formulate effective learning strategies. The design stage was conducted to investigate learning problems in schools. During the design stage, the product was developed according to learning needs. Experts then validated the resulting prototype. After being deemed valid, the product’s practicality was tested by involving students as target users. The practicality testing was done in two stages: one-to-one and small group. In the one-to-one stage, evaluation was conducted individually to understand the user experience. In contrast, in the small group stage, the product was tested on a group of students to gather broader feedback. After meeting practicality standards, the product was implemented in learning through effectiveness testing.

The effectiveness test used a quasi-experimental design, dividing students into control and experimental groups. Before the treatment, both groups underwent a pretest to measure initial abilities. The control group received traditional learning, while the experimental group used AR-based learning. After the learning sessions, both groups were given a posttest to measure differences in learning outcomes.

2.2 Participants

The study involved participation in three stages: validity testing, practicality testing, and effectiveness testing. The validity testing was conducted by four experts (two professors and two doctorate holders in education) through an expert review. The practicality testing and effectiveness testing involved 84 students aged 15–16 years, consisting of 44 male and 40 female students. The practicality testing was carried out through one-to-one (three students) and small group (nine students) formats. The effectiveness testing involved 72 students, with 36 students in the control group and 36 students in the experimental group.

2.3 Data collection and data analysis technique

The data in this study were collected using validity instruments, practicality instruments, and scientific literacy test questions. The instruments for the product validity testing included indicators of material substance, learning design, visual communication display, and software utilization. The Aiken V formula was used to process the validity data.

$$V = \frac{(\text{Score From Expert} - \text{The Lower Score})}{(\text{Number of Category} (\text{Number of Expert} - 1))} \tag{1}$$

The results of the V Aiken data obtained were interpreted by category. The interpretation of the V-Aiken value was based on the number of validators and the Likert scale used to determine the validity level of the developed product. This study involved four experts with a Likert scale assessment range of 1 to 5, indicating that the product was considered valid if the V value was greater than 0.87 [17]. A practicality test instrument was used, which included questions related to ease of use, display design, efficiency, and usability. The practicality testing results were obtained from questionnaire scores filled out by students on a scale ranging from 1 to 5. The test results were processed using percentage techniques.

$$\text{Pr} = \frac{\text{Score Student}}{\text{Maximum Score}} \times 100\% \quad (2)$$

The scoring category of the results of the practicality testing was carried out by dividing the average score of the students by the maximum score, resulting in a percentage value. The product was declared practical if it obtained a score of $\text{Pr} > 80$. For the effectiveness test, the research data was obtained from pretest and posttest scores of scientific literacy abilities in both the control and experimental groups. The test instrument consisted of seven complex multiple-choice questions with four answer choices. The instruments used were scientific literacy instruments in fluid dynamics, tested for validity and reliability. The indicators of the instruments used in scientific literacy were related to the ability to explain scientific phenomena, interpret data, and conduct scientific investigations. The SPSS version 26 application was used to conduct statistical analysis using the Mann-Whitney test. The Mann-Whitney test was applied because the data were not normally distributed or homogeneous. This test aims to examine the research hypothesis, where the null hypothesis (H_0) states that the use of AR does not increase students' scientific literacy in dynamic fluid material. The interpretation of the Mann-Whitney test results in SPSS 26 is based on the significance value. The null hypothesis is accepted if the significance value (P) > 0.05 or the Z value > -1.96 .

3 RESULTS AND DISCUSSIONS

3.1 Preliminary research

The initial research stage aimed to understand the conditions in secondary schools. This process involved a needs analysis that was essential for designing learning materials. The curriculum analysis included examining the synopsis of physics learning materials and the lesson plan to ensure alignment with the expected learning outcomes. Fluid material was a mandatory component for students and encompassed fundamental aspects of physics education related to scientific literacy.

Traditional learning media, such as textbooks and videos, had been used but proved less effective in engaging students. This information was the foundation for developing the AR application to support scientific literacy learning in the classroom. Additionally, the previously applied teaching methods had not optimally supported student engagement. Therefore, it was crucial to integrate the learning model into AR media by implementing the cognitive conflict model to enhance student involvement in the learning process.

3.2 Design or development

The AR product was designed by incorporating every element of the cognitive conflict model stages. Four main menus represent a stage of the cognitive conflict model, guiding users through the learning process. Each menu provides easy access to information on every page of the CCBL model stages. The characteristics of the AR product aligned with the CCBL model stages are presented in Figure 2.



Fig. 2. AR with CCBL stages

Figure 2 illustrates the four stages of the CCBL model within the AR application. In the first stage, activation of preconceptions and misconceptions, information is presented through questions regarding correct or incorrect concepts related to the displayed phenomena to activate students' preconceptions. The second stage, the presentation of cognitive conflict, involves students observing AR simulations and formulating hypotheses based on the phenomena they witness. In the third stage, discovery of concepts and equations, students test their hypotheses through virtual experiments presented in AR on dynamic fluids, such as Bernoulli's equation. Navigation buttons in the AR environment allow students to adjust object positions and collect data. The fourth stage, reflection, consists of assessments in the form of multiple-choice and fill-in-the-blank questions to reflect on the knowledge acquired in the previous stages. Each phase of the AR product facilitates indicators of students' scientific literacy, particularly in explaining scientific phenomena through the presentation of AR objects. Additionally, the availability of a virtual laboratory supports students in conducting scientific investigations and interpreting data. Overall, the interactivity presented in the product includes AR simulations, virtual laboratories, and discussion responses for each syntax of the questions presented.

The advantages of the product were presented in each feature. The AR product with CCBL stages was packaged in an Android package kit (APK) format, a standard format for efficiently installing applications on Android smartphones [18]. The user interface and application system in AR play an essential role in designing an application [19]. The CCBL stage features, in AR form, the AR virtual laboratory, and feedback for each question presented in the application product served as innovations in educational media. Each stage in CCBL played a critical role in improving

students' understanding of concepts through hypothesizing physical phenomena, discovery, and data processing [20]. Teaching techniques involving the presentation and explanation of phenomena were among the efforts to support the advancement of scientific literacy [21]. The interactivity presented in the product encourages student engagement in learning [22]. AR with CCBL stages provides various interactive elements to support students' mastery of scientific literacy abilities in dynamic fluid material.

The validity test results were obtained from the validity instrument involving four experts. The data obtained was quantitative. The data was in the form of product assessment results, including four indicators: material substance, learning design, visual communication, and display software utilization. Each indicator represents the basic components of the developed product. The validity test results are presented in Table 1.

Table 1. The result of the validity test

Indicators	Average
Material Substance	0.95*
Learning Design	0.97*
Visual Communication Display	0.88*
Software Utilization	0.99*
Average	0.95*

Note: *Valid.

Table 1 displayed the results of validity tests from four experts, with the highest score in the material substance indicator being 0.97 and the lowest 0.89, averaging 0.95, which was categorized as valid. The learning design indicator scored between 1 and 0.94, with an average of 0.97, and was also deemed valid, showing that the learning stages were aligned with the model's objectives. The visual communication display indicator had an average score of 0.88, confirming that the interface functioned well. In the Software Utilization indicator, the average was 0.99, indicating that the product was usable on smartphones. Overall, the AR product based on the CCBL model received an average score of 0.95, which was categorized as valid.

The results of the validity test of AR products based on CCBL models in the category were valid. The validity of a product was assessed from the presentation of information that contained the display of communication, material substance, learning design, and software utilization [23]. The products developed meet the standards of the development of digital teaching materials. The material substance of a product contains all material components referred to in the application. The material must be presented clearly and concisely, allowing users to understand it easily [24]. The product has been able to present information on all dynamic fluid materials to obtain valid results. In the visual communication display component, the appearance of an application must be interactive, attractive, and easy to use [24], [25], [26].

Interactivity was presented in the menu display and navigation buttons in applications designed to run normally and obtain valid values. Digital teaching materials in the form of AR must be accompanied by a learning design to guide students to learn systematically by the goals to be achieved [27]. AR applications feature learning design by implementing stages of CCBL models on dynamic fluid materials. The results obtained from the learning design were valid. A digital product must be

able to present the innovation, interest, and originality of software and be able to convey information more effectively [24]. AR products are presented in original and innovative forms by presenting phenomena in the form of AR and can be installed on smartphones as an application. Overall, AR applications designed have met the validity standards of a digital product.

Data practicality test involving 12 senior high school students. The selected students represent low, medium, and high abilities. Ability variations were carried out in practicality tests used to measure the validity of products if used on diverse student abilities. Data on practicality test results were obtained from practicality test instruments. The practicality test instrument contains four question indicators related to the product, including ease of use, appearance, efficiency, and benefit. The results of the practicality test are presented as shown in Table 2.

Table 2. The result of the practicality test

Indicators	% Score of One-to-One	% Score of Small Group
Ease of Use	94*	97*
Attraction	93*	95*
Efficiency	96*	97*
Benefit	93*	94*
Average	94*	95.7*

Note: *Practical.

Table 2 presents the variation in practicality test indicator scores from two stages: the one-to-one stage and the small group stage. The test results showed that the ease of use indicator scored 94% in the one-to-one stage and 97% in the small group stage. The attraction indicator recorded a score of 93% for the one-to-one stage, while the small group stage achieved a score of 95%. For the efficiency indicator, the scores were 96% in the one-to-one stage and 97% in the small group stage. The benefit indicator recorded a score of 93% in the one-to-one stage and 94% in the small group stage. The overall average validity test result in the one-to-one stage was 94%, while in the small group stage, it reached 95.7%. These results indicated that the developed AR met the practicality criteria for a learning product.

The products developed were in the practical category. A product falls into the practical category when it meets indicator standards of ease of use, display design, benefits, and efficiency [28]. Products designed have met the standard components of the practicality of a product. A product was called easy to use when presenting clear and systematic information, making it easier for users to obtain the information presented on the product [29], [30], [31]. Designed products provide a communication display with navigation buttons for moving between pages. Navigation between pages in an application makes accessing the application features easier [32]. Simple and attractive design was the best part of bringing interactivity that was easy for users to understand when learning science material [33]. The product allowed users to access it without problems and run it normally. Digital teaching materials must be developed to provide time efficiency and ease of ownership. The AR application was presented in APK format, allowing free user access by installing it on a smartphone. This condition allows students, as users, to have it without requiring a fee. The application's usefulness must support learning by providing convenience for students to conduct investigations in virtual laboratories [34], [35]. Learning with AR saves

learning time and concisely supports understanding [36]. This application presents AR phenomena and laboratories that benefit students by allowing them to conduct experiments virtually and saving time and space compared to doing it in real conditions. Overall, the AR applications developed meet the element of practicality.

3.3 Assessment phase

The data on the effectiveness test results were obtained from tests of both groups. These results were used to compare the two groups and explore their impact on improving scientific literacy. Since the data obtained were not normally distributed and lacked homogeneity, a comparison test was conducted using the Mann-Whitney test (U). The data presented in this test included the mean (M), standard deviation (SD), Z-value, and significance value (P). The Mann-Whitney test results are presented in Table 3.

Table 3. The result of the Mann-Whitney test

Group	Pretest		Posttest		%N-Gain	U	Z	P
	M	SD	M	SD				
Contol	56	11.4	64	11.6	17%	129.000	-6.12	0.00
Experimental	44	12.4	81	13.4	67%			

Table 3 displayed the mean scores for the control group, with a pretest score of 56 (SD = 11.4), a posttest score of 64 (SD = 11.6), and an increase in %N-gain of 17%. In the experimental group, the average pretest and posttest scores were 44 (SD = 12.4), with an increase in %N-gain of 67%. Both groups showed improvements in scientific literacy abilities. However, the test results showed a U-value of 129.000, indicating a difference between the two groups. The Z-value of -6.12, lower than -1.96, showed that the test results lay outside the critical threshold, reinforcing the indication of a significant difference. This was supported by a P-value less than 0.05, indicating a high significance level. These results revealed a significant difference between the control and experimental groups, confirming that learning using AR significantly improved scientific literacy abilities compared to traditional learning methods.

The AR learning intervention with the stages of the CCBL model successfully improved students' scientific literacy on dynamic fluid material, representing a new finding compared to previous research. This effectiveness test result addressed limitations in prior studies, which only investigated the impact of AR on a single group. Previous simulations, limited to 3D, tested only one group, thus restricting the scope of analysis [37]. In contrast, this study compared two groups to determine the most effective learning method. The product design and instructional approach presented in this study addressed limitations in previous digital media, which presented fluid material solely in flipbook format with limited phenomena depicted as static images [8].

Previous researchers focused on enhancing student motivation and learning outcomes through AR as a learning medium [38], [39], [40]. When applied in the stages of the CCBL model, AR encouraged students to think critically by observing presented phenomena. This model supported practical explanations and helped students deepen their understanding of scientific literacy, particularly in dynamic fluid material. The alignment between AR's advantages and the CCBL model with scientific literacy indicators promoted improvements in students' abilities. AR learning with

the stages of the CCBL model improved students' abilities in explaining phenomena, interpreting data, and conducting investigations in a dynamic fluid material.

Augmented reality played a role in explaining phenomena presented at each stage of the CCBL model. The CCBL model activated students' preconceptions and misconceptions in the first stage by assessing their prior knowledge [14]. AR provided visualizations of phenomena to build students' foundational knowledge. The second stage involved presenting cognitive conflict and training students to write hypotheses about the presented phenomena. AR explained these events in detail, while object visualizations helped enhance students' scientific literacy in describing and investigating physical phenomena. AR in physics learning offered numerous benefits for improving the quality of learning and student outcomes [41], [42].

The fourth stage of the CCBL model was concept discovery and equation formulation. Virtual laboratory activities and data collection became the main focus of this stage. AR was presented as a virtual lab for data collection, which stimulated students' learning interest [40], [43]. Exploration activities in the AR lab helped students gather and interpret data, training their scientific literacy and data-based interpretation skills. Concept refinement and mastery of deeper thinking skills through AR also provided a more accurate picture of students' learning outcomes [44], ensuring this model effectively contributed to cognitive development.

Augmented reality presentations displayed realistic physics objects in real-world contexts, stimulating students' curiosity to explore physics material further through AR objects. Visualizing phenomena in presenting cognitive conflict aimed to encourage students to sharpen and enrich information to explain the phenomena. Learning with AR-enabled students to explore, observe, and simulate physical phenomena, helping them explain physics material more specifically. AR's capabilities are aligned with the characteristics of scientific literacy indicators. The CCBL model with AR improved students' scientific literacy in a dynamic fluid material.

4 CONCLUSION

Aligned to improve scientific literacy in education, this study successfully developed an AR application integrated with the stages of a CCBL model for dynamic fluid material. The developed AR application was validated in content, instructional design, visual communication display, and software utilization. Practicality test results indicated that the developed product was practical regarding ease of use, display design, efficiency, and benefits. The effectiveness test results demonstrated that the AR application significantly improved students' scientific literacy compared to traditional learning methods. Overall, the AR application designed with the characteristics of the CCBL model stages proved valid, practical, and effective, serving as an innovative solution to improve students' scientific literacy in physics learning.

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