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Design and Validity of a Cognitive Conflict-Based Physics Educational Game to Support Students' Conceptual Understanding of Rectilinear Motion Material

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ABSTRACT

Understanding concepts is important in learning physics because it helps students connect theories with real-life phenomena, develop scientific reasoning, and avoid misconceptions. However, in practice, physics learning still faces challenges, especially in the topic of straight-line motion. One solution is an educational physics game based on cognitive conflict, which is expected to improve students' concept understanding and correct misconceptions. This research is a type of development research using the Plomp development model. The educational game developed is based on cognitive conflict and consists of four stages: 1) Activating prior knowledge and misconceptions, 2) Presenting cognitive conflict, 3) Discovering concepts and equations, and 4) Reflection. The validity results for the physics educational game are V = 90, which is in the very valid category, and the practicality results are 92.48, which is in the very practical category. Based on these results, it can be concluded that the physics educational game based on cognitive conflict for improving students' concept understanding in the topic of straight-line motion meets good validity criteria and can be used in the learning process as an interactive teaching material.

INTRODUCTION

Education plays a key role in building a nation because it helps create young people who are ready to face future challenges. In the era of globalization, the education system is changing, and learning must keep up with the times. The main challenge in education today is how to develop human resources with 21st-century skills, such as critical thinking, creativity, communication, and collaboration. Wijaya et al. (2016) emphasize that these skills are very important for meeting the demands of the times. In addition to high-level thinking skills, students also need to be able to adapt to technological advancements in order to contribute more effectively to the understanding of knowledge. A student's ability to understand concepts is very important in learning physics (Putri & Perdana, 2023).

One of the subjects that plays a key role in developing high-level thinking skills is physics. Learning physics demands a strong conceptual understanding as well as critical and analytical thinking skills. Entinol et al. (2022) state that each concept in physics is interconnected and forms a comprehensive understanding of natural phenomena. Understanding concepts in physics is not simply about memorizing formulas; it must include a deep understanding of the principles and their applications in everyday life. Based on their level of mastery, students' conceptual understanding can be categorized as understanding the concept, experiencing misconceptions, or not understanding the concept. Yuli & Mufit (2021) explain that identifying this level of understanding is crucial in determining appropriate learning strategies. Without a strong conceptual understanding, students will have difficulty grasping advanced material, such as linear motion, which is the foundation of various other physics concepts (Juniartini., el al).

A good understanding of linear motion is crucial because it serves as the foundation for learning advanced concepts such as dynamics, energy, and momentum. However, many students struggle to differentiate between fundamental concepts such as velocity, acceleration, and distance traveled, often leading to misconceptions. Rahmadani et al. (2023) demonstrated that these misconceptions are a major obstacle to learning because they can disrupt students' understanding of overall physics concepts. The phenomenon of poor understanding and comprehension of concepts is an issue that often arises in science learning, especially in physics learning (Mufit et al., 2023). These errors often arise from everyday experiences that shape students' prior knowledge, which is inconsistent with scientific concepts (Mufit & Fauzan 2019).

This study conducted a preliminary study at SMAN 2 Koto XI Tarusan to determine students' conceptual understanding using a test instrument consisting of 17 five-tier multiple choice questions on linear motion material. This instrument has been tested as valid and reliable (Hidayatullah & Mufit, 2023). Based on the test results, the level of students' concept understanding was found in class XI Fase F. A small number of students fully understood the concepts, most experienced misconceptions, and a small number did not understand the concepts at all. These results show that students' understanding of straight-line motion is still very low, with misconceptions being the main problem that needs to be addressed through more effective and interactive learning models.

Research shows that misconceptions in physics learning can hinder the proper mastery of concepts (Mufit & Fauzan, 2019). In addition, Aini & Mufit (2022) found that students' understanding of the concept of straight-line motion is still quite low, and there is a lack of effective teaching materials or multimedia that can help improve their conceptual understanding. One model that can be used to overcome this problem is a cognitive conflict-based learning model. Mufit et al. (2023) explain that this model works by challenging students' initial understanding by presenting situations that contradict their existing conceptions. Madu & Orji (2015) state that when students' cognitive balance is disturbed by new, conflicting information, cognitive conflict occurs, triggering a deeper learning process.

Using the cognitive conflict model has been shown to effectively improve students' understanding of concepts. Mufit (2018) explains that this model can update erroneous conceptions and improve learning outcomes. Rachmawati & Supardi (2021) add that this model is also effective in reducing pre-existing misconceptions. In the context of current technological developments, digital-based learning is a relevant and adaptive solution. One innovation in digital learning is the use of educational games. Educational games can present interactive and enjoyable learning, while encouraging students' cognitive engagement through visualization and simulation of concepts. Yakin et al. (2018) state that the use of educational games has also been shown to increase students' learning motivation. Magdalena et al. (2020) add that educational games provide a more engaging learning experience than conventional methods.

Various studies have developed innovative teaching materials to support linear motion learning. Ayopma and Mufit (2023) created a teaching material based on cognitive conflict that has been proven valid and is suitable for use. Meanwhile, Simaremare et al. (2022) developed an augmented reality-based educational game on kinematics. However, the development of physics education games that specifically integrate cognitive conflict learning models as teaching materials to improve students' understanding of linear motion concepts is still very limited. Therefore, this research aims to develop a physics education game based on cognitive conflict that is valid and suitable for use as teaching material to enhance students' conceptual understanding and reduce misconceptions about linear motion.

METHODS

Types and Procedures of Research

This research is a type of development research (Development Research) that aims to develop and validate a product so that it is suitable for use in learning. The development model used is the Plomp model which consists of three stages, namely: (1) preliminary research, (2) development or prototyping, and (3) assessment phase (Plomp & Nieveen, 2013). The product developed is a cognitive conflict-based physics educational game to improve students' conceptual understanding of linear motion material. The first stage, preliminary research, includes needs analysis or problem analysis. At this stage, students' conceptual understanding is assessed using a five-tier multiple-choice instrument, which has been tested for validity and reliability (Hidayatullah & Mufit, 2023). Additionally, interviews were conducted with three physics teachers at SMAN 2 Koto XI Tarusan to understand the physics teaching practices at the school.

The second stage is the development or prototyping phase. In this stage, the physics educational game was designed using Construct 2, with development steps such as creating backgrounds and object animations using the Canva application, creating a programming prototype (coding), and creating an APK file. After the initial design was completed, a self-evaluation was conducted by the researchers to assess the completeness and suitability of the design to the planned format. After that, expert validation was conducted by three physics lecturers from the Faculty of Mathematics and Natural Sciences, UNP, to provide input used in revising the prototype. The revised product was then tested on three students of SMAN 2 Koto XI Tarusan through a one-to-one evaluation activity. The selected students represented the categories of low, medium, and high academic ability. This trial aimed to assess the game's readability and ease of use in learning.

Research Instrument and Data Analysis Techniques

The instruments used in this study consisted of an expert validation sheet and a student practicality sheet. The validation sheet was designed to assess important aspects of the developed physics educational game, while the practicality sheet was used to reveal students' views on the game as a teaching material for linear motion. Data analysis aims to answer the problem formulation and evaluate product feasibility. Product validity was analyzed using the Aiken index (Aiken's V), which measures the level of agreement between raters on the quality of items in the validation instrument. The Aiken's V value is calculated using the formula:

$$V = \frac{\sum s}{n(c-1)} \qquad (1)$$

$$s = r - l_0 \qquad (2)$$

Where r is the score given by the assessor, l_0 is the lowest score (i.e., 1), c is the highest score (i.e., 5), and n is the number of assessors. The results of Aiken's V score are then categorized as follows: a score less than 0.88 is categorized as invalid and a score greater than 0.88 is categorized as valid. A product is considered valid and suitable for use if its validity score is in the valid category (Aiken, 1985).

Meanwhile, a practicality analysis was conducted based on the results of a questionnaire administered to students. The practicality score was calculated by comparing the obtained score with the maximum score, then multiplied by one hundred to obtain a percentage. The interpretation of the percentage results was categorized as follows: a percentage between 81–100% is categorized as "very practical," 61–80% is categorized as "practical," 41–60% is categorized as "quite practical," 21–40% is categorized as "less practical," and 0–20% is categorized as "not practical." Products are considered practical and suitable for use if they are included in the practical or very practical category (Khairul Anshari et al., 2019).

RESULTS AND DISCUSSION

Results

The results of the development in this research, namely a cognitive conflict-based physics educational game using Construct 2 by making it into an Android package (apk) format. The educational game has 3 main menus, including: (1) Instructions, (2) Competencies, and (3) Materials. Each part is connected to one another so that users can also get the results obtained from each activity they do through reflection.

Figure 1. Cover View

The cover of this cognitive conflict-based physics educational game on linear motion features a bright and engaging look with a calming natural feel. In the center, a large, brightly colored title stands out, emphasizing that the game focuses on learning the concept of linear motion using the cognitive conflict model. The background features a blue sky, white clouds, green trees, and a stretch of grass, creating a fresh and enjoyable experience for students. On the left side, a child riding a bicycle represents the phenomenon of linear motion in everyday life, while on the right side, a bee and a small creature represent enemies to be avoided in the game. The bright orange “Start” and “Exit” buttons are placed in the center, easily accessible, and reinforce the impression of a simple yet functional design. Overall, this cover reflects the spirit of learning physics that is fun, interactive, and close to students' real experiences.

The main menu page contains several features that act as shortcuts to open the application's menu displays. The features in the main menu include instructions, competencies, materials, compilers, and references. The main menu display can be seen in Figure 2.

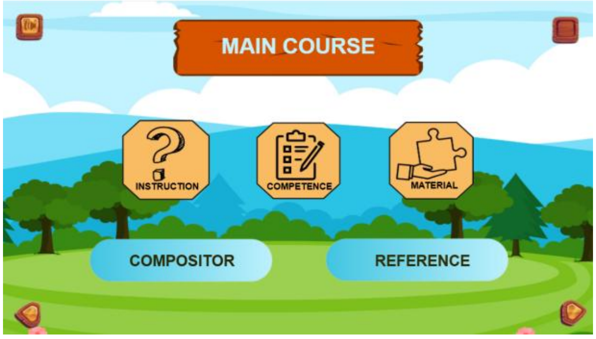

Figure 2. Main Menu Display

The main menu contains the menu features that are available and accessible when using the educational game. There are three main features: instructions, competencies, and materials. First, the instructions feature contains steps that users must understand before using the educational game. Second, the competencies feature contains competencies that students must achieve in the linear motion material based on the Merdeka Curriculum. Finally, the materials feature consists of a selection of linear motion materials. The display of the material options in the physics educational game can be seen in Figure 3.

Figure 3 displays the material selection menu in a cognitive conflict-based physics educational game on linear motion. This menu serves as an entry point for users to select the sub-material they wish to learn, namely Uniform Linear Motion (GLB), Uniformly Accelerated Linear Motion (GLBB), Upward Vertical Motion, Downward Vertical Motion, and Free Fall. Each material is symbolized by easily recognizable visual icons such as cars, balls, and apples to help students relate physics concepts to real-world phenomena. This interface is designed to be simple, brightly colored, and user-friendly so that students can navigate the game easily and are motivated to explore each motion concept.

Figure 3. Select Material Menu Display

After selecting a material, players are immediately directed to the game. In the game, players control a character to complete missions. Each mission requires players to find four master keys, which are scattered throughout the game. While searching for the keys, players are given lives to survive. Lives decrease when players are attacked by enemies. If a life runs out, the game starts over. The game also features holes that players must avoid; falling into a hole will also cause the game to start over. Throughout the game, players also collect crystals to increase their point score. The more crystals collected, the more they motivate players to continue progressing toward completing their missions.

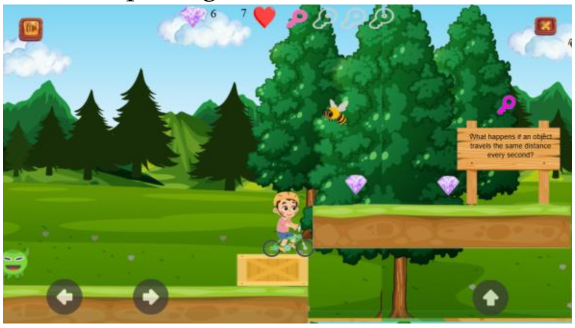

Figure 4. Initial view of the game starting

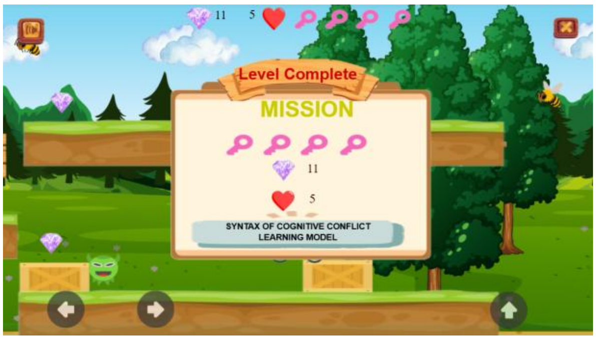

Figure 5. Game view after completing the mission

Figure 5 shows the final page after successfully completing a cognitive conflict-based physics educational game about straight motion. This screen displays the message "Mission Complete," indicating that the player has successfully completed the game and can proceed to the cognitive conflict learning stage. The center of the screen displays the number of points earned, in the form of keys, crystals, and hearts, indicating that the four keys have been successfully found and can proceed to the cognitive conflict-based learning stage. The crystals represent rewards for successfully collecting during the game, and the hearts represent the number of lives remaining after completing the game. The background features a natural setting with trees and a clear sky, maintaining an educational and fun feel. The bright visual design, animated elements, and clear achievement indicators help increase students' motivation and sense of accomplishment after completing each learning level. Overall, this screen demonstrates successful learning while encouraging students to move on to the next stage.

The preconception and misconception activation stage begins with the viewing of an animated video depicting phenomena relevant to the concept being studied. This video aims to build connections with students' everyday experiences and explore any preconceptions or misconceptions they may have. After watching the video, students are asked questions that stimulate their initial thinking. After answering these questions, a score will appear as a measure of the students' prior knowledge.

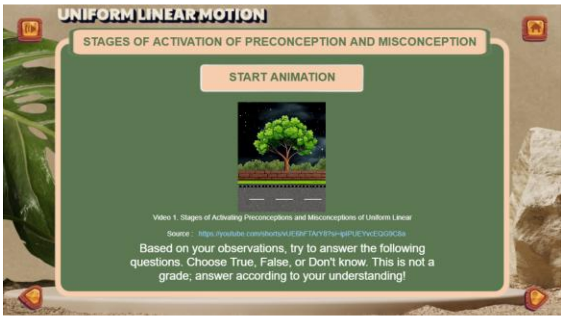

Figure 6. Display of questions at the preconception and misconception activation stage

Figure 7. Display of the score obtained after completing the questions at the preconception and misconception activation stage.

In the cognitive conflict presentation stage, students are asked to formulate a hypothesis regarding the questions posed after watching the animated video. The animated video depicts a phenomenon that contradicts the students' preconceptions, creating confusion or a discrepancy between the initial answer (prediction) and the reality presented. This situation triggers cognitive conflict within the students.

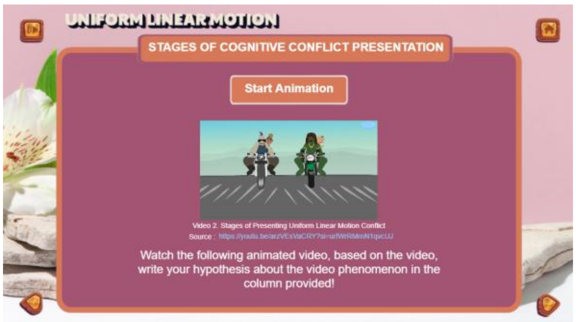

Figure 8. Display of instructions for the stages of presenting cognitive conflict

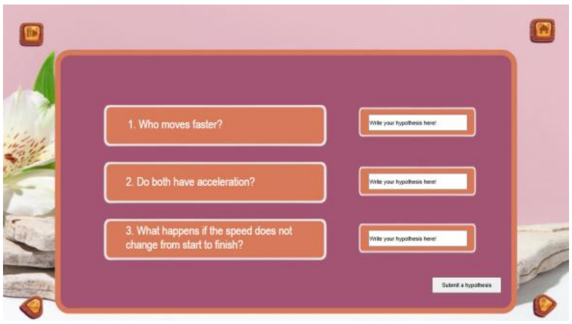

Figure 9. Display of questions at the cognitive conflict presentation stage

Concept and equation discovery stage, at this stage students are directed to analyze data from simulations, virtual practicum results tables, or simple graphs to discover and understand physical concepts scientifically. Concept and equation discovery stage: At this stage, students are directed to analyze data from simulations, virtual lab results tables, or simple graphs to discover and understand physics concepts scientifically. Answers are submitted based on the analysis of the virtual lab work and the conclusions drawn from the completed data tables.

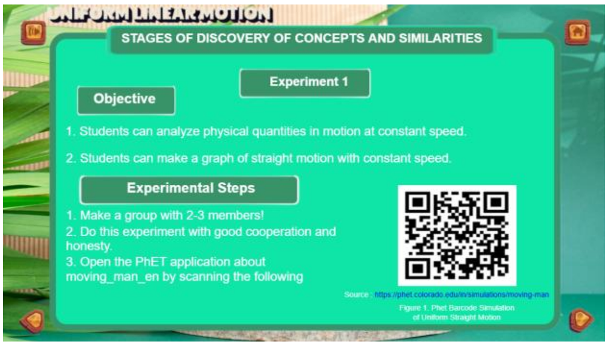

Figure 10. Initial view of the concept and equation discovery stages

Reflection Stage, at this stage students are asked to answer four-tier multiple choice questions with reasons, then the system automatically provides feedback on the classification of understanding, namely: understanding the concept, misconception or not understanding the concept. After knowing the results of the understanding categories that have been carried out, they can then see the correct answers and discussion of the related questions.

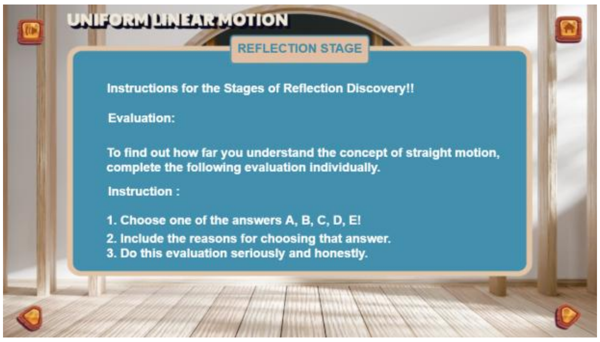

Figure 11. Display of reflection stage instructions

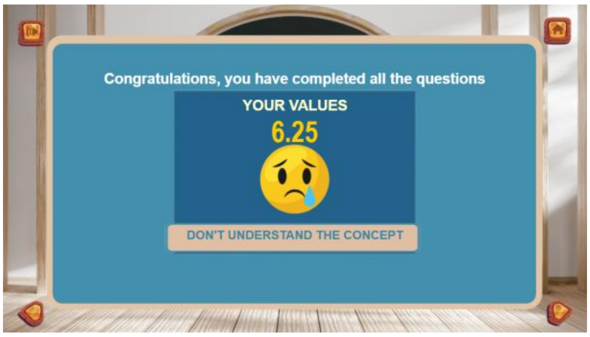

Figure 12. Display of values and categories of conceptual understanding after completing the reflection stage.

The developed educational game was then tested to determine whether it met the needs. The testing consisted of two tests: validity and practicality. The testing consists of two types of assessments: validity testing and practicality testing. The validity test was conducted by three physics department lecturers from the UNP Faculty of Mathematics and Natural

Sciences. The experts evaluated based on four criteria: 1) the content of the material, 2) the design of the learning game, 3) the visual communication, and 4) the use of software.

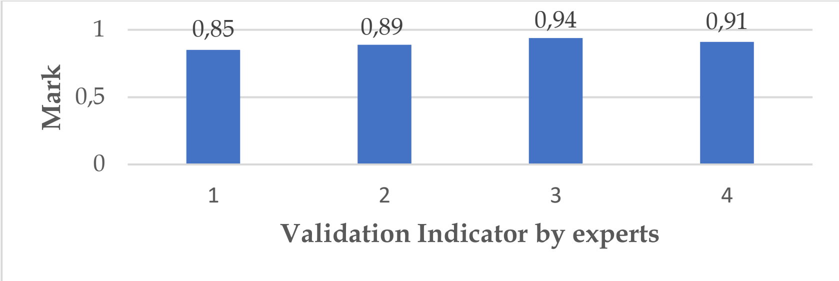

Figure 13. Results of validation indicators by experts

Figure 13 shows the average expert validation score for each aspect of the physics educational game. The score was 0.85 for the material substance aspect, 0.89 for the learning design aspect, 0.94 for the visual communication display aspect, and 0.91 for the software utilization aspect. The overall average score for the physics educational game was 0.90. Thus, the expert validation score for the cognitive conflict-based physics educational game on the straight motion material is categorized as valid.

Based on the validity test, the educational game has high validity. This validity is assessed from four aspects: the content material, the learning design, the visual communication presentation, and the use of software. A study by Socrates, Ikram, et al., (2023) supports this finding, as the educational game they developed achieved an average validity score of ≥ 0.88, which is included in the valid category.

This practicality test was conducted on three students in a one-on-one session. The game's practicality was determined after the product was validated and then revised according to the validator's suggestions. After the game was used during classroom learning, students completed a practicality questionnaire. The results of the practicality test for the one-to-one stage can be seen in the figure.

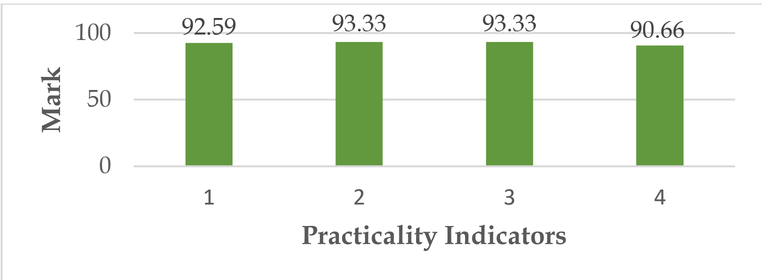

Figure 14. Results of the Practicality Indicator for the One to One Stage

Figure 14 shows the average values of each component in the practicality of the Physics educational game in the one to one setting. The ease of use component has a value of 92. 59, attractiveness is 93. 33, efficiency is 93. 33, and benefit is 90. 66. Based on these values, it can be stated that the practicality of the Physics educational game falls into the very practical category. The overall average value of all practicality indicators is 92. 48. Therefore, the Physics educational game based on cognitive conflict to improve students' understanding of linear motion concepts has practicality in the very practical category during the one to one stage.

Based on the practicality test results from the one-to-one stage, the physics education game is classified as very practical. The practicality characteristics were assessed in four aspects: ease of use, attractiveness, efficiency, and usefulness. All four aspects received an average score above 90. Similar findings were reported in a study by Panggayudi et al. (2017), which showed that educational games are well-suited for students because they align with students' preferences for exploration, visual learning, and learning through play. In addition, research by Socrates, Ikram, et al., (2023), also strengthens this finding, where the developed physics educational game showed practicality test results for one to one of 91.9% and small groups of 90.4%, both of which are included in the very practical category.

Discussion

A cognitive conflict-based physics educational game on linear motion demonstrated excellent validity and practicality. The product has high validity, with an Aiken's V score of 0. 90, showing that the material content, learning design, visual communication, and use of software all meet the expected quality standards. These findings are consistent with the research by Socrates, Ikram, et al. (2023), who also found high validity in the development of game-based media for physics learning.

This successful validity is inseparable from the systematic implementation of the cognitive conflict model integrated into the learning syntax. The use of animated videos, simulations, and conceptual problems can elicit discrepancies between students' preconceptions and the phenomena presented. This strategy aligns with cognitive conflict theory, which has been proven effective in various previous studies (Hermawan et al., 2008).

Furthermore, the results of the one-to-one practical phase showed that this educational game was highly practical, with an average score of 92.48%. This shows that the game is easy to use, engaging, efficient, and offers real benefits in the learning process. These findings are supported by research from Panggayudi et al. (2017), which states that educational games are well-suited for students because they fit the exploratory, visual nature and preference for game-based learning that students tend to have.

The integration of technology, cognitive conflict models, and interactive design provides an innovative advantage in this game. Compared to previous research that only emphasized visual aspects or educational narratives, this game incorporates a cognitive conflict-based approach explicitly designed within four learning syntaxes, providing significant opportunities for students to independently reconstruct their concepts.

Developing a physics educational game requires considerable time to complete the product to ensure its suitability for use as teaching material in schools. This physics educational game can be accessed on Android and iOS devices. The development of the physics educational game in this study was limited to linear motion. Therefore, further development of physics educational games for other physics topics is needed. Furthermore, this study only reached the stage of one-to-one practical testing with students. Future researchers can continue the process to the assessment phase for optimal results.

However, a limitation of this study is that it has not conducted extensive effectiveness testing and is limited to linear motion. This presents an opportunity for further development, expanding the scope of the material and conducting larger-scale trials with quantitative analysis of student learning outcomes. Future research is also expected to include comprehensive assessments of students' critical and conceptual thinking skills to test the long-term impact of using cognitive conflict-based educational games in physics learning.

CONCLUSION

A physics education game based on cognitive conflict learning has been developed. It is structured according to the cognitive conflict-based learning model, which includes four steps: 1) Activating prior knowledge and misconceptions, 2) Presenting cognitive conflict, 3) Discovering concepts and connections, and 4) Reflection. The product includes several supporting components such as a cover, main menu, instructions, competencies, cognitive conflict learning syntax, materials, authors, and references. The validity of the physics educational game was 90, categorized as valid, and the practicality of the physics educational game was 92.48, categorized as very practical. This shows that a physics education game based on cognitive conflict can be used in the learning process as an interactive teaching material. Therefore, it is hoped that further studies are conducted to examine the effectiveness of this physics education game based on cognitive conflict in improving students' understanding of the topic of linear motion. Physics educational games designed to improve conceptual understanding can be developed for other physics topics.

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