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Design of Educational Game-Based Teaching Materials Using Cognitive Conflict for Particle Dynamics

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ABSTRACT

Conceptual understanding plays a crucial role in physics learning because it enables students to connect theory with real phenomena, build scientific reasoning, and prevent misconceptions. However, the reality of learning shows that students' conceptual understanding, especially of Newton's laws, is still low. This condition calls for innovation in teaching materials, one of which is through the development of educational games based on the cognitive conflict learning model. This study aims to develop a valid and practical cognitive conflict learning model-based physics educational game to improve students' conceptual understanding. The research includes development research using the Plomp model, which consists of preliminary research, development or prototyping, and assessment stages. The research was limited to one-to-one practicality testing. Data were obtained through a preliminary study of students in classes XI F4 and XI F5 taught by physics teachers at SMA Pembangunan Laboratorium UNP. Validation was carried out by three physics lecturers from FMIPA UNP, while practicality testing was carried out on three students in class XI Fase F at the same school. The research instruments included open-ended questionnaires, concept comprehension tests, teaching material needs questionnaires, self-evaluation sheets, validity sheets, and practicality sheets. Data analysis used descriptive, V Aiken, and percentage techniques. The results showed that students needed technology-based teaching materials to improve their concept comprehension. The physics educational game on Newton's Law material was successfully developed with excellent quality. The self-evaluation results were 96 percent, the average validity was 0.93, and the practicality was 90.06 percent, all of which were categorized as very good. The game was declared valid and practical for use in high school physics learning and will be followed up with an effectiveness test of the educational game product.

Keywords: Physics educational game, Cognitive Conflict, Conceptual Understanding, Newton's Laws.

I. INTRODUCTION

Education is a conscious and systematic effort to impart cultural values, knowledge, and skills to future generations [1]. Education is also the main foundation for the transmission of values, knowledge, and skills, and plays a strategic role in promoting national progress[2]. In the education system, curricula such as the Merdeka Curriculum play a fundamental role in shaping outstanding students through the integration of 21st-century skills[3]. However, the development of these skills cannot be optimized without strong conceptual mastery [4], which is an essential competency and reflects deep thinking processes [5]. Physics, which is a subject at the high school/MA level, has a strategic role in fostering critical thinking, scientific reasoning, and problem-solving skills. Mastery of physics concepts is the foundation for success in further studies in science and

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Technology [6]. Along with advances in science and technology, the integration of technology in learning, such as the concept *of e-learning*, is important to create an interactive, engaging, and relevant learning experience[7]. In addition, the development of an adaptive and responsive curriculum is also necessary so that students are able to compete in this era of the 4.0 industrial revolution. Thus, physics education will not only produce a deep understanding of concepts, but also practical skills that are relevant to the needs of today's world of work [8].

Despite its vital role, physics learning at the high school level is often considered difficult by students, especially when it comes to Newton's Laws. This difficulty stems from the abstract and complex nature of physics concepts [9], causing students to tend to memorize formulas rather than engage in reasoning and deep conceptual understanding[10]. This difficulty results in high levels of misconceptions found in almost all physics topics, including Newton's First and Second Laws, with misconception rates reaching 62.98% and 52.35%, respectively[11].

Preliminary research conducted at SMA Pembangunan Laboratorium UNP using *a four-tier multiple choice test* reinforces these findings. The data shows that students' level of conceptual understanding of Newton's Laws is low in both classes, with a dominant percentage of misconceptions (average 38.41%). The highest misconception (68%) was found in indicators related to understanding Newton's Second Law. These findings are reinforced by research conducted by Hikmah Amalian, which shows that students often have difficulty understanding Newton's laws, especially the concept of force. Several forms of misconceptions identified include: (1) the assumption that weight is always equal to normal force, (2) the assumption that action and reaction forces act on the same object, (3) the equation of mass and weight, and (4) the belief that the greater the mass of an object, the greater the force produced [12].

The low level of conceptual understanding and high level of misconceptions, which was confirmed by the teacher questionnaire, was caused by a conventional (*teacher-centered*) learning approach and limited teaching materials that could remedy students' misconceptions. As a result, they have difficulty understanding physics material, as evidenced by the results of a needs survey that showed students had difficulty understanding physics material. On the other hand, they have a high interest in interactive teaching materials (average score of 3.0–3.2) and educational games (average score of 3.0–3.3). In addition, digital facilities such as *smartphones* and internet access are also relatively high (average 3.1–3.3).

Therefore, interactive teaching materials are needed to overcome misconceptions and improve students' understanding of concepts. Interactive teaching materials are comprehensive (*self-contained*) teaching materials designed to encourage meaningful mental and physical interaction and learning activities. The material is structured to enable students to learn independently (*self-instructional)* without direct dependence on educators [13]. Interactive teaching materials provide two-way interaction between students and learning materials, allowing students to be more actively involved in the learning process [14]. Conflict-based educational games are considered highly relevant given that research shows that most teenagers spend 1-3 hours playing *games* every day [15].

Educational games are a form of game designed to provide learning experiences through interactive and easy-to-understand media, thereby helping to improve students' understanding of concepts in a more in-depth and enjoyable way. Educational *games* can create a more enjoyable learning atmosphere and make it easier for students to understand the material being studied. The Cognitive Conflict Model focuses on problem investigation and is specifically designed to address misconceptions through four syntaxes: (1) preconception activation, (2) cognitive conflict presentation, (3) concept discovery, and (4) reflection [16]. By integrating the syntax of this model into *educational games*, it is hoped that learning will become more interesting, misconceptions will be remedied, and students' understanding of Newton's laws will improve.

II. METHOD

Type and procedure of research

This study employed development research aimed at producing and validating a usable instructional product. The research adopted the Plomp development model, which consists of three main phases: (1) initial needs analysis, (2) design and prototype development, and (3) evaluation and revision [17]. The final product of this study was a cognitive conflict–based physics educational game designed to improve Grade XI students' conceptual understanding of particle motion dynamics in senior high schools (SMA/MA). The initial phase focused on identifying learning problems and instructional needs. A four-tier multiple-choice conceptual understanding test was administered to students to identify misconceptions related to particle motion dynamics. This instrument had previously undergone validity and reliability testing [18]. In addition, an analysis of the need for educational game–based teaching materials was conducted through classroom observation and an open-ended questionnaire distributed to a Grade XI physics teacher at SMA Pembangunan. The results of this phase served as the basis for determining content scope, learning objectives, and game features.

In this phase, the educational game prototype was designed and developed using the Construct 3 application. The development process included designing visual backgrounds and object animations using Canva, followed by programming and game logic development through coding. After completing the initial prototype, a self-evaluation was conducted by the researchers to assess the completeness, consistency, and alignment of the design with the predefined learning objectives and cognitive conflict principles. This step ensured that the prototype met minimum technical and conceptual standards prior to expert validation.

Subsequently, expert validation was carried out by three physics education lecturers from FMIPA Universitas Negeri Padang. The validators evaluated the product in terms of content accuracy, pedagogical appropriateness, and media quality. The level of validity was calculated using Aiken’s V coefficient, where a value of $V \geq 0.80$ was interpreted as high validity. Revisions were made based on expert feedback. The revised prototype was then subjected to a one-to-one evaluation involving three Grade XI students from SMA Pembangunan Laboratorium. This evaluation aimed to examine the clarity of presentation, ease of use, and initial effectiveness of the game as a learning medium

Research instruments

The instruments used in this study consisted of a needs analysis sheet, a validity test sheet, and a practicality test sheet. The needs analysis sheet was used for data collection, while the validity assessment sheet was filled out by six lecturers from the Physics Department of FMIPA UNP, consisting of three subject matter experts and three teaching material experts. In addition, there was also a practicality sheet used in the one-to-one evaluation stage for students.

Data Analysis Techniques

Data analysis techniques relate to the calculation processes used to answer problem formulations and test proposed hypotheses. In this study, data analysis was conducted in three stages, namely preliminary research analysis, development analysis, and final product analysis. Preliminary research analysis aims to identify the needs and problems that form the basis for product development. Development analysis includes the data processing process during the product design and manufacturing stages. Meanwhile, final product analysis is carried out through product validity calculations and practicality tests using the *one-to-one evaluation* method on the developed product.

1. Preliminary research analysis

a. Concept comprehension instrument analysis

The concept comprehension instrument is calculated through quantitative scoring based on predetermined criteria. The scoring results are then processed to determine the level of students' comprehension of the concepts being tested. The data obtained is analyzed using a four-level multiple-choice test scoring guide with the following conditions: if the answer or reason given is correct, it is given a score of 1, while if the answer or reason given is incorrect, it is given a score of 0.

$$Final\ score = \frac{\sum \text{Answer score} + \text{Reason score}}{\sum Maksimum\ score} \times 100$$

Next, to identify the types of answers given by students, a *four-point multiple-choice test* result interpretation guide was used. Based on this guide, students were classified into four categories: understanding the concept, understanding part of the concept, not understanding the concept, and experiencing misconceptions.

b. Analysis of student needs questionnaire

The student needs questionnaire was analyzed using descriptive analysis techniques. The data obtained will be analyzed using the formula:

$$X = \frac{\sum X}{N}$$

X = Average score
N = Number of respondents
$\sum X$ = total score of respondents' answers on an item/theme

2. Product validity analysis

The validity of the developed product was obtained through a validity instrument filled out by lecturers from the Physics Department of Padang State University (UNP). The validity test assessment questionnaire was compiled based on a Likert scale to assess the level of suitability, clarity, and feasibility of each aspect of the developed product. The assessment data was then analyzed using Aiken's validity index (Aiken's V), which was used to measure the level of agreement among experts on each assessment item. The Aiken index value was obtained using the following formula:

$$V = \frac{\sum s}{n(c - l_0)}$$

$$s = r - l_0$$

Explanation:

V = Rater agreement index
lo = The minimum validity rating value
c = The maximum validity score
r = The score assigned by an evaluator
n = The total number of evaluators

After obtaining the inter-rater agreement index, the next step is to determine the category based on the index value. The determination of the assessment category is based on Aiken's V Index, as shown in the following table.

Table 1. Decisions Based on Aiken's V Index

Interval	**Validation Category**
≤ 0.4	Insufficient
$0.4 < V \leq 0.8$	Moderate
$0.8 < V$	Hight

The product is considered suitable for use if the validity is in the moderate and high categories [19].

3. Practicality Analysis

The practicality of the physics education game on Newton's Law material to assess high school/MA students' comprehension of the concept was gathered from the questionnaire responses completed by students after using the product. The practicality assessment questionnaire was compiled based on the Likert scale, which aims to determine the level of ease, attractiveness, usefulness, and effectiveness of using games in the learning process. The Likert scale used in this assessment consists of five assessment categories as shown in the following table:

Table 2. Likert scale

Likert Scale	Assessment
1	Strongly Disagree
2	Disagree
3	Agree
4	Strongly agree

[19]

The practicality test data obtained was analyzed using the equation.

$$Value = \frac{Total\ Weight}{Maksimum\ Weight} \times 100$$

Practicality assessment was determined based on the interpretation criteria obtained as shown in the table below.

Table 3. Product Practicality Criteria Achievement

Level	Category
86% - 100%	Highly practical
76% - 85	Practical
60% - 75	Moderately practical
55% - 59	Less Practical
≤ 54	Not Practical

A product is considered practical and suitable for use if it is rated as practical or very practical [20].

III. RESULTS AND DISCUSSION

Results

The results of this study are a cognitive conflict-based physics educational game developed using Construct 3 and presented in HTML5 link format, so that it can be accessed directly through a browser without the need to install an application. This educational game is designed to help students understand Newton's laws through a cognitive conflict approach that encourages them to think critically and reconstruct their understanding of correct physics concepts. This educational game has three main menus, namely: (1) instructions, which contain instructions on how to use and play the game; (2) Competencies, which contain learning objectives and competency achievements to be attained; and (3) Materials, which present physics concepts packaged through cognitive conflict-based activities. These three menus are interconnected so that users can follow the learning flow systematically and obtain feedback in the form of reflections from each activity carried out during play. The cover of the Physics educational game that has been created can be seen in Figure 1.

Fig.1. Initial interface (cover page) of the physics educational game based on the cognitive conflict model for Newton's Laws material

The main menu contains a number of features that serve as quick access to the application's sections. The elements available on the menu include instructions for use, competencies, materials, information about the authors, and a list of references. The main menu is visualized in Figure 2.

Fig. 2. Main Menu

The main menu provides a set of features that can be accessed while playing the learning game. There are three core components, namely guidelines, competencies, and learning materials. To begin with, the instructions section contains the steps that students need to understand before playing this educational game. Second, the competencies section displays the learning outcomes that students must achieve in Newton's Law material in accordance with the 2025 BSKAP provisions. Third, the material section presents content options related to Newton's laws. The visualization of material selection in the physics educational game is shown in Figure 3.

Fig. 3. Material

Then, users are automatically directed to the game stage. In this phase, players control a character to complete a series of missions that have been provided. Each mission requires players to obtain crystals as the key to unlocking or entering the learning model syntax stage. During the crystal collection process, players are given a number of lives as a limit of endurance. Lives are reduced when the character is attacked by enemies, and if the number of lives reaches zero, the game restarts from the beginning. Additionally, there are obstacles in the form of holes that must be avoided because falling into them also causes the game to return to the starting point. Throughout the game, players also collect coins that serve as a motivational element to encourage mission completion. The educational game area is shown in the following image:

Fig. 4. Game

After players obtain the first crystal, the system automatically displays the preconception and misconception activation stage. At this stage, users first watch an animated video that displays phenomena in accordance with the physics concepts being studied. The video presentation aims to build connections with the students' real-life experiences and identify any preconceptions or misconceptions that may have been formed previously. After the video is played, students are given trigger questions to stimulate their initial thinking. The preconception and misconception activation phase is shown in the following figure:

Fig. 5. Activation of Preconceptions and Misconceptions

The preconception activity display consists of learning video clips as initial triggers for student understanding.

Fig. 6. Preconception and Misconception Activation Questions

Preconception questions containing initial comprehension questions to identify students' initial concepts

Fig. 7. Feedback on Preconception Activation and Misconceptions

Display of positive feedback to students after answering questions correctly.

After the players complete the first syntax, the game continues with the search for the second crystal as access to the stage of presenting cognitive conflict. During this phase, students are encouraged to develop hypotheses based on the questions presented after they have watched an animated video. The video shows phenomena that are inconsistent with the students' initial preconceptions, thus creating a discrepancy between their predictions and the reality shown. This condition is deliberately designed to trigger cognitive conflict in students. The second syntax is shown in the following figure.

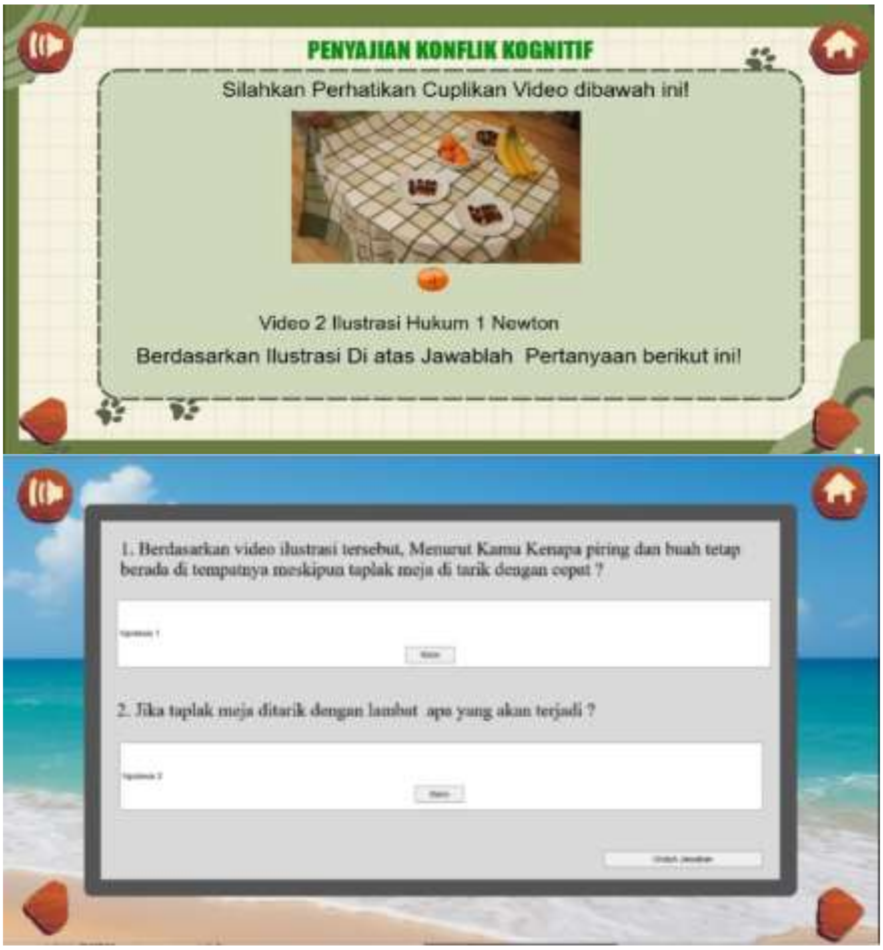

Fig. 8. Cognitive Conflict Presentation Questions

After completing the second syntax, players continue the game to obtain the third crystal as access to the stage of discovering concepts and equations In this phase, students are guided to analyze the data presented through virtual simulations, virtual experiment result tables, or simple graphs. These activities aim to help students identify and understand scientific physics concepts through Phet simulations.

Fig. 9. Concept and Equation Discovery

After players complete the third syntax, the game continues to obtain the fourth crystal as the key to the reflection stage. At this stage, students are given multiple-choice questions to answer. After students provide their answers, the system automatically displays feedback in the form of a classification of their level of understanding, namely grasping the concept, experiencing misconceptions, or having an incomplete understanding of the concept. The reflection stage display is shown in the following figure.

Fig. 10. Reflection stage display

Fig. 11. Reflection Stage Feedback

The educational game was created and later evaluated to assess its suitability for learning needs. The evaluation process was carried out through two types of testing, namely tests of validity and practicality. The validity assessment was conducted by three lecturers from the Department of Physics, Faculty of Mathematics and Natural Sciences, UNP. The experts' evaluation focused on four main aspects, namely: (1) the suitability of the material content, (2) the design of game-based learning media,(3) visual communication, and (4) software utilization. The visualization of the validity assessment results by experts on the physics educational game is presented in the following figure

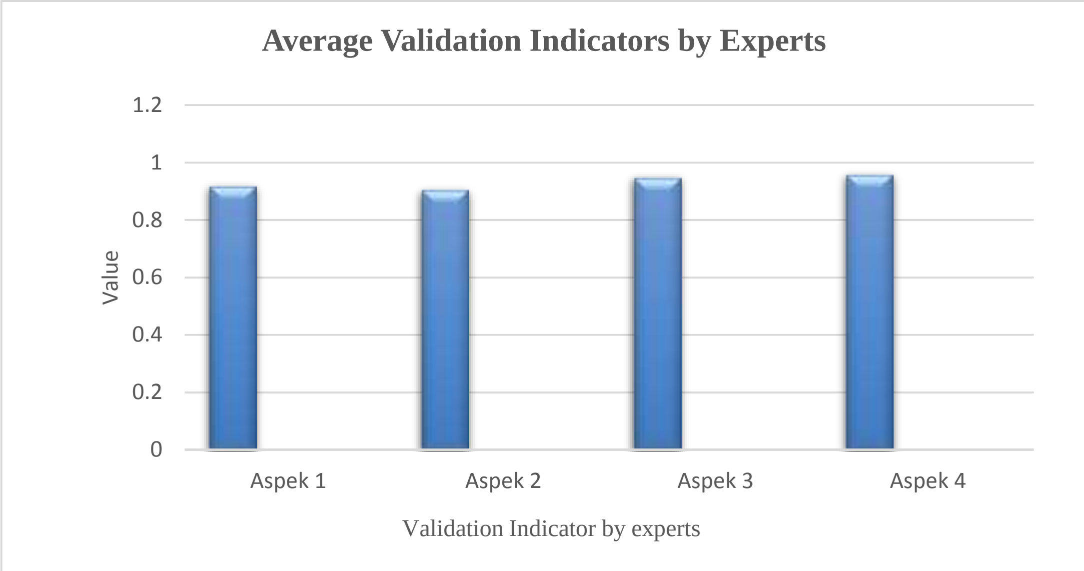

Fig. 12. Average Validation Indicators by Experts

The average validation results from the four main aspects of product development, presented in Figure 23, collectively show a very high and consistent level of validity, with values ranging from 0.908 to 0.960. Aspect 4 recorded the highest value of 0.960, followed by Aspect 3 (0.950) and Aspect 1 (0.920). Meanwhile, Aspect 2 was the lowest with a value of 0.908. Since all aspects have achieved values above 0.90, it can be concluded that each product component is in the Highly Valid category. Overall, the average validation score for all aspects is 0.9345, confirming the quality and readiness of the product for further testing.

Practicality tests were conducted on three students through one-to-one sessions, each representing the high, medium, and low ability categories. Practicality assessments were carried out after the product had undergone a validation process and been revised in accordance with expert recommendations. Next, the educational game teaching materials were used in classroom learning activities, and students were asked to fill out a practicality questionnaire after completing the learning process. The outcomes of the practicality assessment during the one-to-one stage are displayed in the figure below.

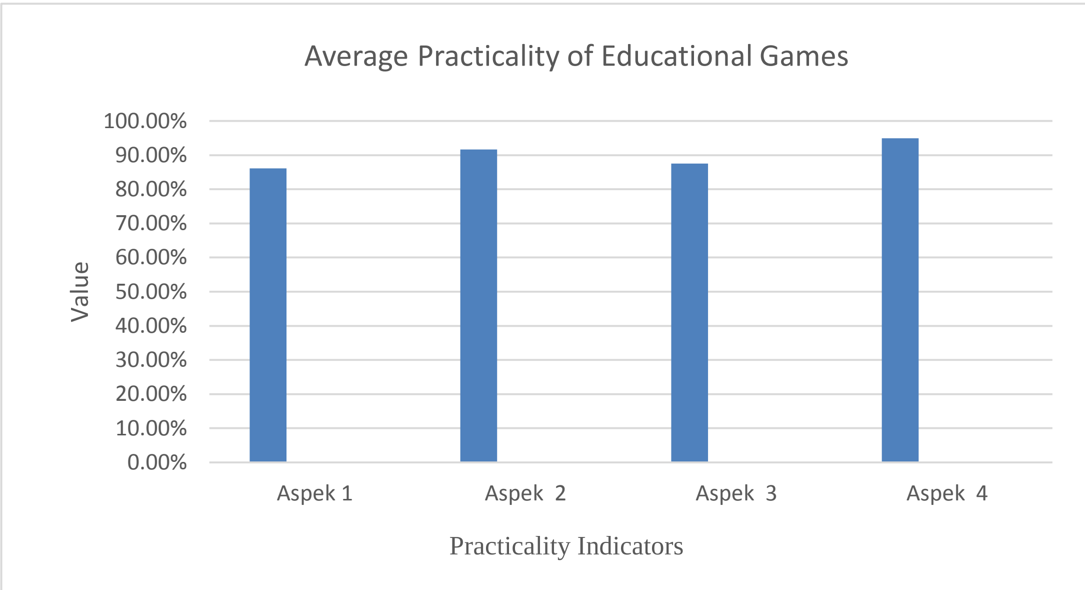

Fig. 13. Average Practicality of Educational Games

The practicality test results indicate that the developed physics instructional material has a very high level of practicality, with assessment indicator values ranging from 86.10% to 100% and an overall average score of 90.06%. The ease of use aspect scored approximately 86%, indicating that the instructional material is easy for students to understand and use. Students reported that the learning instructions were clear and that the learning stages could be followed well, resulting in minimal difficulty during the learning process.

The attractiveness aspect achieved a score of around 92%, showing that the visual design, animations, and learning activities successfully attracted students' attention and increased their engagement. The efficiency aspect scored approximately 88%, indicating that the instructional material supports effective use of time and a well-structured learning flow. Meanwhile, the benefit aspect obtained the highest score, at around 95%, demonstrating that the instructional material strongly supports students' understanding of physics concepts and promotes independent learning. Overall, these results confirm that the developed physics instructional material is highly feasible for learning implementation.

Discussion

This development research resulted in physics instructional material in the form of an educational game based on the cognitive conflict learning model for Newton's Laws. The needs analysis conducted during the *preliminary research* stage indicated that students' conceptual understanding remained at a low level and was dominated by misconceptions, particularly on indicators related to Newton's Second Law, the direction of motion, and the identification of forces acting on objects. The identified misconception patterns—such as the belief that force is always in the direction of motion or that a force must continuously act for an object to keep moving—indicate that students' conceptual understanding is still largely based on everyday intuition rather than scientific principles. These findings reinforce previous studies reporting that misconceptions in Newton's Laws are persistent and occur across almost all subtopics [21].

Data obtained from student and teacher needs questionnaires provide deeper context for these findings. Student responses indicate that difficulties in understanding abstract physics concepts are closely related to the limitations of the instructional materials currently used, which are still dominated by textbooks and verbal explanations. Meanwhile, teachers reported that learning activities tend to focus on direct formula delivery, resulting in limited student involvement in conceptual exploration and construction. This condition aligns with constructivist perspectives, which argue that meaningful learning cannot be achieved when students act merely as passive recipients of information[22]. Therefore, the development of instructional materials that activate students' prior conceptions and facilitate conceptual reconstruction is highly necessary.

The developed physics educational game integrates the four stages of the cognitive conflict learning model into the gameplay structure. Theoretically, cognitive conflict functions as a trigger for *cognitive disequilibrium*, encouraging students to revise their existing conceptions toward scientifically accurate understanding. The implementation of cognitive conflict through interactive simulations and immediate feedback enables students not only to recognize their misconceptions but also to comprehend the scientific reasoning behind conceptual corrections. Thus, the instructional material goes beyond information delivery by facilitating active learning oriented toward conceptual discovery and reflection.

Expert validation results indicate that the instructional material falls into the *very valid* category in terms of content substance, instructional design, visual communication, and software utilization. This high level of validity demonstrates that the integration of the cognitive conflict model into the educational game has been implemented consistently and is aligned with the learning outcomes of the Merdeka Curriculum. The alignment among learning objectives, gameplay flow, and content strengthens the potential of this instructional material as a tool for conceptual learning rather than merely a supplementary medium. These results are consistent with the findings of [7] , who reported that physics educational games with strong pedagogical design tend to achieve high validity.

In the one-to-one practicality test, the physics educational game obtained an average score of 90.06%, placing it in the *very practical* category. Beyond the percentage scores, qualitative analysis of student responses revealed that students were supported by clear usage instructions, a well-structured gameplay flow, and the presence of simulations and animations that facilitated conceptual understanding. Students stated that the game activities helped them maintain focus, reduced learning boredom, and enabled them to understand the relationships among force, mass, and acceleration more concretely. Visual attractiveness and interactivity were identified as key factors in sustaining student engagement during the learning process.

The efficiency and benefit aspects also yielded highly positive results. Students reported that the game could be used independently with minimal teacher assistance and helped optimize learning time due to its structured and concept-focused presentation. The high scores on the benefit aspect indicate that the instructional material is not only technically practical but also pedagogically meaningful, as it supports conceptual understanding and has the potential to reduce misconceptions. These findings are consistent with previous studies by [23] and [24], which showed that cognitive conflict-based instructional materials demonstrate high practicality and effectively support independent concept construction.

Nevertheless, this study has several limitations that should be considered. The practicality test was limited to the one-to-one stage; therefore, the obtained responses do not fully represent the diversity of student characteristics in larger classroom or school contexts. In addition, practicality data were collected through questionnaires, which tend to reflect students' perceptions rather than actual learning behaviors. These limitations restrict the generalizability of the findings. Accordingly, future research is recommended to proceed with *small group evaluations* and *field tests*, as well as to combine questionnaires with observations and interviews to obtain a more comprehensive understanding of the instructional material's effectiveness.

Overall, the findings indicate that the cognitive conflict-based physics educational game demonstrates high validity and excellent practicality, and it has strong potential as an interactive instructional material that supports concept-based physics learning. With further development on other physics topics and broader-scale testing, this instructional material may contribute significantly to contextual physics learning that aligns with the demands of 21st-century education

IV. CONCLUSION

This study developed physics instructional materials in the form of an educational game based on the cognitive conflict learning model, which underwent expert validation and practicality testing. The validation results showed an average score of 0.93, categorized as *highly valid*, indicating that the instructional materials meet the eligibility criteria in terms of content substance, instructional design, visual appearance, and technical quality. Meanwhile, the practicality test yielded a percentage of 90.06%, categorized as *very practical*, demonstrating that the instructional materials are easy to use, engaging, efficient, and supportive of students' understanding of Newton's Laws concepts.

From a pedagogical perspective, the use of cognitive conflict-based physics educational games has the potential to promote active learning, facilitate conceptual change, and reduce students' misconceptions through the presentation of cognitive conflict, interactive simulations, and immediate feedback. Therefore, these instructional materials are feasible to be used as interactive teaching materials to support the improvement of students' conceptual understanding in physics. However, this study was limited to expert validation and one-to-one practicality testing. Future research is recommended to conduct small-group trials and field testing to examine the effectiveness of the instructional materials in improving students' learning outcomes and conceptual understanding. In addition, further development can be carried out on other physics topics to broaden the scope and enhance the relevance of cognitive conflict-based educational games to the demands of 21st-century physics learning.

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