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Design and Validity of a Cognitive Conflict-Based Physics Educational Game to Support Students' Conceptual Understanding of Temperature and Heat

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ABSTRACT

Conceptual understanding is a crucial aspect of physics education because it enables students to connect theoretical concepts with everyday phenomena, develop scientific reasoning, and minimize the occurrence of misconceptions. However, students' conceptual understanding of temperature and heat remains a challenge in physics education. One approach is to develop a cognitive conflict-based physics educational game that facilitates a learning process focused on conceptual understanding. This study employed a design research approach using Plomp's development model. The educational game developed incorporates four stages of cognitive conflict: (1) activation of preconceptions and misconceptions, (2) presentation of cognitive conflict, (3) discovery of concepts and equations, and (4) reflection. Product validation was conducted by three validators, all of whom were experts in physics education, while the practicality test was conducted on a one-on-one basis with three students with high, moderate, and low academic abilities. The results showed that the physics educational game achieved a validity score of 0.94, classified as "highly valid," and a practicality score of 93.66, classified as "highly practical." Based on the results of the validation and practicality testing, the cognitive conflict-based physics educational game on the topics of temperature and heat is deemed valid and practical for use as interactive teaching material in physics education.

Keywords: *Educational Game, Cognitive Conflict, Conceptual Understanding, Physics Education.*

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I. INTRODUCTION

The 21st century has been marked by rapid advancements in science, technology, and information that have influenced nearly every aspect of life, including education. Education is expected to produce high-quality graduates with strong competitiveness[1] . These changes are evident in various aspects, including the curriculum, learning models, teaching methods, and instructional materials used[2].The main challenge is how to develop human resources with 21st-century competencies, namely critical thinking, creativity, communication, and collaboration. One subject that contributes to the development of these skills is physics, as it requires a deep conceptual understanding. However, there are still various challenges in creating an effective educational system to enhance students' conceptual understanding, particularly in physics.

Physics encompasses a collection of theories, laws, principles, rules, and formulas organized according to its subject matter[3] . As a branch of the natural sciences, physics examines various natural phenomena and their applications in everyday life. Every learning activity has a specific objective, and in the context of physics education, these objectives are closely tied to students' ability to understand their environment and solve various problems, both during the learning process and in real life [4] . Therefore, conceptual understanding is a crucial aspect that must be addressed to ensure students can engage optimally in the physics learning process.

Conceptual understanding refers to a person's ability to accept and interpret a mental representation of knowledge that has been generalized based on various similar phenomena. In science education, conceptual understanding is not merely about memorizing formulas but also involves a deep mastery of physics principles and their application in daily life. Based on their level of mastery, students can be categorized as having a good grasp of concepts, holding misconceptions, or lacking conceptual understanding[5]. Students' success in learning physics is also determined by the extent to which they master the concepts being studied[6] . Students' ability to understand facts and events is acquired through the learning process and their experiences. In physics education, conceptual mastery is one of the key indicators of success in science learning[7]. One of the problems still encountered in physics education is students' low level of conceptual mastery. This situation can influence the conceptions formed in students and has the potential to create a discrepancy between their initial understanding and correct scientific concepts—a phenomenon known as a misconception. Thus, the challenges in physics education are not only related to low learning outcomes but also to how to identify and correct students' conceptions that do not align with scientific concepts.

Misconceptions are one of the main obstacles in physics learning. According to research by Mufit & Fauzan (2019)[5], misconceptions in physics learning can hinder students from understanding concepts correctly. These misunderstandings often arise from everyday experiences that lead students to develop their own theories, which may not necessarily align with scientific concepts. Furthermore, research by Aini & Mufit (2022)[8] indicates that students' conceptual understanding remains relatively low and that there is a lack of instructional materials capable of enhancing their conceptual understanding. This situation suggests that many students still experience misconceptions and difficulties in grasping concepts, thereby necessitating more effective and innovative instructional models to address these issues.

In this study, a preliminary study was conducted at SMAN 5 Pariaman to assess students' conceptual understanding using a test instrument consisting of 15 five-tier multiple-choice items on the topics of temperature and heat. This instrument has been validated and found to be reliable[9] . Based on the test results, the level of conceptual understanding among students in Class XI Phase F showed that a small portion of students understood the concepts correctly, the majority held misconceptions, and a small portion did not understand the concepts at all. These results indicate that students' conceptual understanding remains very low, with misconceptions being the primary issue that needs to be addressed through more effective and interactive learning models.

The application of the cognitive conflict learning model is one approach that can be used to improve students' conceptual understanding. Mufit (2018)[10] revealed that this model can help students correct conceptions that do not align with scientific concepts and improve learning outcomes. In line with this, Rachmawati & Supardi (2021)[11] stated that the application of cognitive conflict can help reduce misconceptions that students previously held. With the advancement of technology, the use of digital-based learning has become a relevant alternative to support the learning process. One form of this innovation is the use of educational games as a learning medium. Educational games can create interactive and enjoyable learning experiences and encourage students' cognitive engagement through visual presentations and concept simulations.

Based on the identified issues, the use of cognitive conflict-based physics educational games is essential for improving students' conceptual understanding. These educational games will make learning more engaging and encourage students to visualize abstract phenomena and concepts. Therefore, this study aims to develop and determine the validity and practicality of a cognitive conflict-based physics educational game for the topics of temperature and heat.

II. METHOD

Type and Research Procedure

The research type used is design research, a type of research aimed at developing and validating a product to ensure it is suitable for use. The development model used is the Plomp " " model, which consists of three stages: (1) Preliminary Research; (2) Development or Prototyping Phase; (3) Assessment Phase[12]. The product developed is a cognitive conflict-based physics educational game designed to improve students' conceptual understanding of temperature and heat. The first stage, the preliminary research, involved a needs analysis or problem analysis. During this stage, students' conceptual understanding was assessed using a five-tier multiple-choice instrument that met validity and reliability criteria[9] . Additionally, interviews were conducted with two physics teachers at SMAN 5 Pariaman to gather information about the physics learning process implemented at the school.

The second stage was the development or prototyping phase. In this stage, the physics educational game was developed using Construct 2 through several steps: designing the background and object animations using the Canva application, creating a prototype through the programming process, and producing the final product in the form of an APK file. After the initial design was completed, the researcher conducted a self-evaluation to assess the completeness and suitability of the design according to the established format. Next, validation was conducted by three physics lecturers from the Faculty of Mathematics and Natural Sciences (FMIPA) at UNP. This validation aimed to gather feedback and suggestions as a basis for revising the prototype. The revised prototype was then tested through a one-on-one evaluation involving three students from SMAN 5 Pariaman representing low, medium, and high academic ability levels. The trial was conducted to assess the game's readability, ease of use, and practicality in supporting the learning process.

Research Instruments and Data Analysis Techniques

The instruments used in this study included an expert validation form and a student practicality form. The expert validation form was used to assess various aspects related to the feasibility of the developed physics educational game. Meanwhile, the student practicality form was used to determine students' responses to the use of the physics educational game as teaching material for the topics of temperature and heat. The data obtained were then analyzed to address the research questions and determine the level of suitability and practicality of the developed product. The validity of the product was analyzed using Aiken's V index, which is used to determine the level of agreement among validators regarding the quality of each item on the validation instrument. The Aiken's V value was calculated using the following formula:

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

$$S = r - 1_0 \qquad (2)$$

In this formula, r represents the score given by the rater; 1_0 represents the lowest possible score (1); c represents the highest possible score (5); and n represents the number of raters. The resulting Aiken's V value is then interpreted based on validity criteria. A V value < 0.88 is categorized as "invalid," while a V value ≥ 0.88 is categorized as "valid." Thus, the product is deemed valid and suitable for use if it obtains a validity score falling within the "valid" category[13].

Meanwhile, the practicality analysis was conducted based on the results of a questionnaire administered to the students. The practicality score was obtained by comparing the score achieved with the maximum possible score, then multiplying the result by 100% to determine the practicality percentage. These percentage results were then interpreted based on the following criteria: 81–100% falls into the "very practical" category, 61–80% into the "practical" category, 41–60% into the "fairly practical" category, 21–40% into the "less practical" category, and 0–20% into the "impractical" category. A product is deemed practical and suitable for use if it achieves a percentage falling within the "practical" or "very practical" categories[14] .

III. RESULTS AND DISCUSSION

Results

The outcome of this research is a cognitive conflict-based physics educational game developed using Construct 2 and packaged as an application. This educational game consists of three main menus: (1) Instructions, (2) Competencies, and (3) Materials. These three menus are designed to work together to support the learning process. Each activity in the game also includes a reflection stage, allowing students to understand and evaluate the results of the learning activities they have completed.

Figure 1. Cover Screen

The cover is the opening page of the educational game that displays the lesson title and several key features, such as the start and exit buttons. Sec Overall, the cover design is intended to represent engaging, interactive, and contextual physics learning, thereby creating a positive first impression and connecting the lesson material to students' everyday experiences. The main menu page contains various features that serve as navigation tools for accessing different sections of the application. Available features include instructions, competencies, materials, authors, and references. Each feature is designed to make it easier for users to access the information and materials contained in the physics educational game. The main menu page is shown in Figure 2.

Figure 2. Main menu display

The main menu provides several features that users can access while using the physics educational game. The first feature is "Instructions," which contains information on how to use the game so that users can understand its operation. The second feature is "Competencies," which lists the learning outcomes students need to master in the material being studied in accordance with the Merdeka Curriculum. The final feature is "Materials," which contains various learning sections organized according to the topics covered. The materials selection screen in the physics educational game is shown in Figure 3.

Figure 3. Content selection interface

Figure 3 shows the material selection menu in the cognitive conflict-based physics educational game for the topics of temperature and heat. This menu serves as a navigation tool for users to select the subtopics they wish to study based on their learning needs. After selecting the material, the player is directed straight to the game section. At this stage, the player controls the character to complete the mission by finding four main keys scattered throughout various parts of the game. While carrying out the mission, the player is given 8 lives, which serve as the limit on the number of attempts to complete the game. Lives are lost whenever the character is hit by an enemy attack. If all lives are lost, the game must be restarted from the beginning. Additionally, there are several obstacles in the form of holes that must be avoided. If the character falls into a hole, the game will also reset to the beginning.

Figure 4. The game’s starting screen

Figure 5. Screen after completing the game

Figure 5 shows the final screen that appears after the player successfully completes the cognitive conflict-based physics educational game on the topic of temperature and heat. This page displays the message “Win Game” to indicate that the player has successfully completed the mission and can proceed to the next stage of cognitive conflict-based learning. The use of bright visual design, animated elements, and clear achievement indicators provides students with feedback on their success. Thus, this page not only marks the completion of the game but also encourages students to move on to the next stage of learning. The stage for activating preconceptions and misconceptions begins with the presentation of an animated video illustrating phenomena related to the learning concepts. The presentation of these phenomena aims to connect the material to students’ everyday experiences while identifying their prior knowledge and potential misconceptions. After watching the video, students are given several questions to explore their initial understanding of the presented phenomena. Students’ answers are then scored and displayed to provide an overview of their prior knowledge level before entering the next learning stage.

Figure 6. Display of the preconception and misconception activation stage

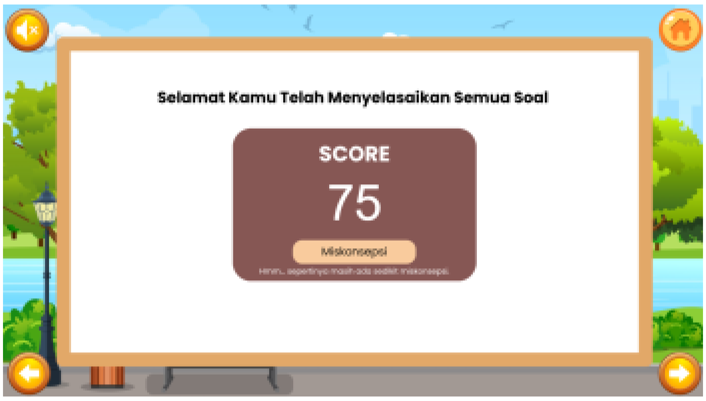

Figure 7. Display of scores obtained after answering questions

In the cognitive conflict presentation stage, students are guided to formulate hypotheses based on questions provided after watching an animated video. The video presents a phenomenon that does not align with students' prior understanding or predictions. The discrepancy between the anticipated answers and the presented phenomenon casts doubt on the students' prior understanding. This situation subsequently triggers a cognitive conflict, which serves as the basis for students to reevaluate their understanding of the concept being studied.

Figure 8. Display of the cognitive conflict presentation stage

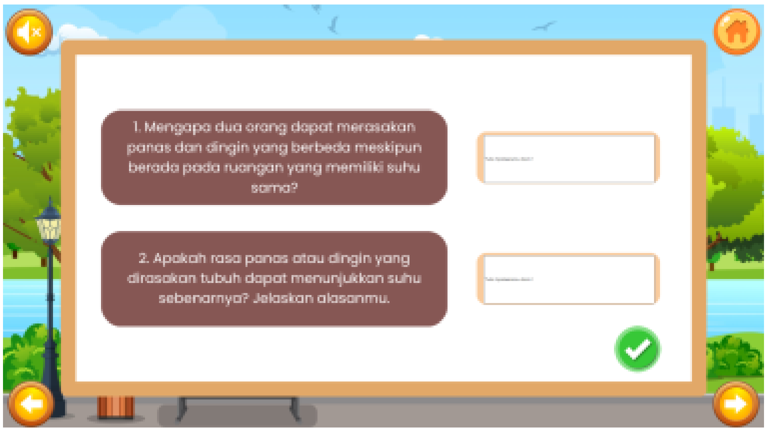

Figure 9. Display of questions during the cognitive conflict presentation stage

The Concept and Equation Discovery stage is designed to analyze data obtained from experiments, lab result tables, or simple graphs to discover and understand physics concepts scientifically. Students analyze the results of the virtual lab and the data obtained, then use this as a basis for answering questions. Next, students draw conclusions based on the results of their analysis of the completed data tables. This stage helps students build conceptual understanding based on the results of their observations and analysis, rather than solely on the information provided.

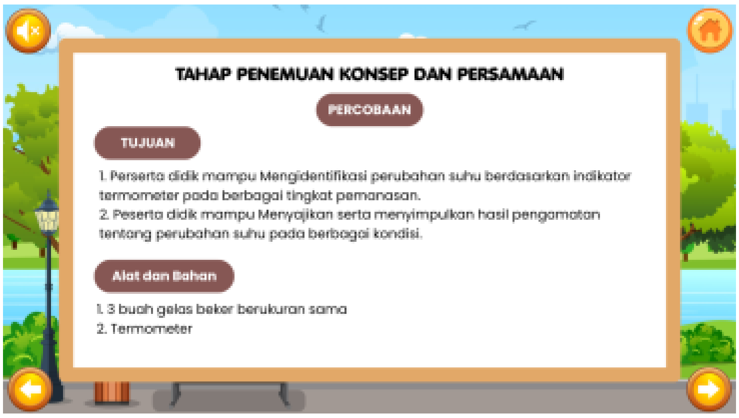

Figure 10. Initial screen of the concept and equation discovery stage

In the reflection stage, students are asked to answer four-level multiple-choice questions accompanied by justifications for their chosen answers. Based on the students' responses, the system automatically identifies and provides feedback on the students' understanding categories: understanding the concept, holding a misconception, or not understanding the concept. After receiving these results, students can view the correct answers along with explanations for each question. This stage helps students evaluate their understanding and correct any concepts they have not yet grasped properly.

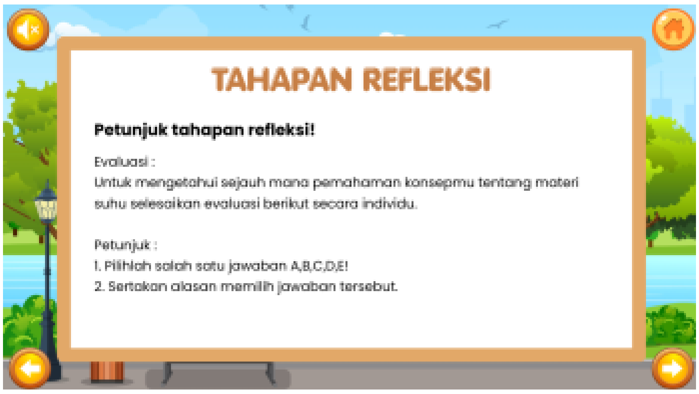

Figure 11. Initial view of the reflection stage

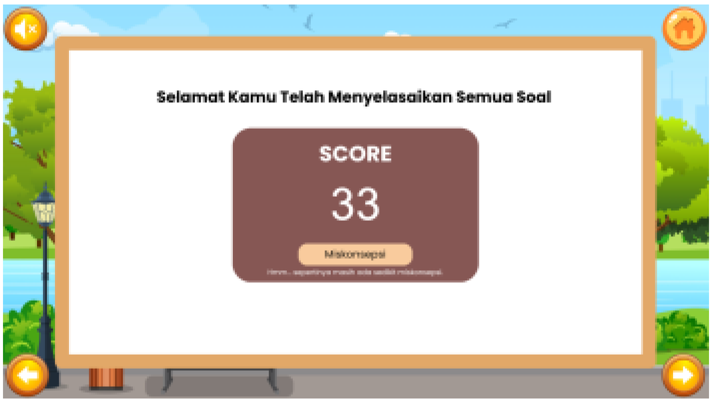

Figure 12. Assessment screen of the reflection stage

The educational game that has been developed was then tested to determine its feasibility and suitability for learning needs. Product testing included validity and practicality tests. The validity test was conducted by three physics lecturers from the Faculty of Mathematics and Natural Sciences, UNP. The validity assessment covered four aspects: (1) content substance, (2) instructional design, (3) visual communication, and (4) software utilization. The assessment results from the validators were used as the basis for determining the level of validity and making improvements to the developed product.

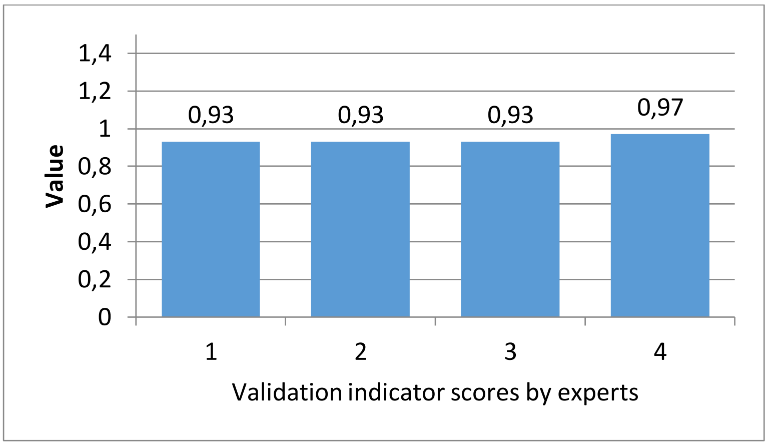

Figure 13. Validity indicator results by experts

Figure 13 shows that the validation indicator scores by the experts ranged from 0.93 to 0.97. The average validation score for the validity indicators by the experts was 0.94. Thus, the expert validation score for the cognitive conflict-based physics educational game on the topics of temperature and heat is categorized as highly valid. The practicality test was conducted during the one-on-one evaluation phase, involving three students representing low, moderate, and high academic ability levels. This test was carried out after the product had undergone the validation process and been revised based on suggestions from the validators. During the pilot phase, students used the educational game in their learning activities and then completed a practicality questionnaire to evaluate the product. The practicality assessment covered four aspects: (1) ease of use, (2) appeal, (3) efficiency, and (4) benefits. The results of the practicality test during the one-on-one evaluation phase are presented in Figure 14.

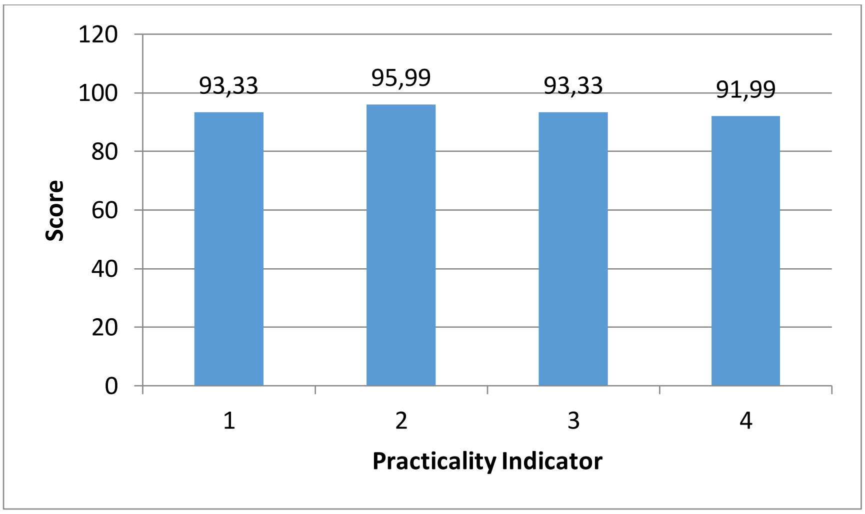

Figure 14. Practicality Indicators

Figure 14 shows that the practicality indicator scores ranged from 91.99 to 95.99. The average practicality score for the validity indicator, as assessed by the experts, was 93.66. Thus, the practicality score for the cognitive conflict-based physics educational game on the topic of temperature and heat is categorized as highly practical.

Discussion

This study produced physics instructional materials in the form of an educational game developed based on the cognitive conflict learning model for the topics of temperature and heat. The results of the needs analysis in the preliminary research phase indicated that students' level of conceptual understanding was still relatively low, with conditions largely characterized by the presence of misconceptions. Data obtained through student and teacher needs questionnaires further reinforced these findings. Based on student feedback, difficulties in understanding abstract physics concepts were influenced by limitations in the instructional materials used, which largely still relied on textbooks and verbal explanations. On the other hand, teachers reported that the learning process still tended to focus on direct instruction, so opportunities for students to explore concepts, develop reasoning, and build understanding independently remained relatively limited.

The cognitive conflict-based physics educational game developed for the topics of temperature and heat demonstrated excellent levels of validity and practicality. The validation results yielded an Aiken's V score of 0.94, indicating that the product meets the criteria for high validity. This high validity score is supported by evaluation results across four aspects: content substance (0.93), instructional design (0.93), visual communication (0.93), and software utilization (0.97). These scores indicate that every component of the game aligns very well with the objectives and characteristics of the developed instructional medium. The software utilization aspect received the highest score, at 0.97. This indicates that the use of Construct 2 is considered highly appropriate for supporting game development, as it enables the integration of various learning elements—such as animations, videos, simulations, interactivity, navigation, and assessment—into a single medium. Meanwhile, the identical score of 0.93 for the aspects of content substance, instructional design, and visual communication indicates that these three aspects also met the validity criteria well. These results align with previous research showing that game-based learning media for physics instruction have a high level of validity[15] .

The success of the product validation was supported by the systematic application of the cognitive conflict model, which was integrated into the learning stages. The use of animated videos, simulations, and conceptual problems was designed to create a discrepancy between students' prior understanding and the presented phenomena, thereby encouraging students to reexamine their existing understanding. This integration enables the game to function not only as a medium for delivering content but also to support students' process of constructing and refining their conceptual understanding. Furthermore, the use of visual and interactive elements helps present the concepts of temperature and heat in a more concrete and engaging manner. Thus, the high validity score not only indicates the appropriateness of the content but also reflects the coherence between the subject matter, the cognitive conflict-based instructional design, the visual presentation, and the use of software in supporting the learning objectives.

Furthermore, the results of the practicality test in the one-to-one phase indicate that the developed educational game falls into the "highly practical" category, with an average score of 93.66. These results demonstrate that the game offers ease of use, appeal, efficiency, and significant benefits in supporting the learning process. The product's high practicality is primarily supported by a game design that is simple, interactive, and easy for students to operate. Students can follow the game's flow and access learning materials and activities without encountering significant difficulties. Appeal stands out as the most prominent aspect, indicating that the use of game elements, animations, visuals, and interactive activities enhances student engagement during the learning process. These features make learning more engaging and help students maintain their concentration, preventing them from becoming easily bored.

The practicality of the game is further supported by the systematic organization of learning materials and activities. Students can progress through the learning process via stages integrated into the game's narrative, making the learning process more focused and reducing the need for intensive teacher supervision. Furthermore, combining content, games, and learning activities into a single medium enables students to learn more independently. This demonstrates that the practicality of games is not only related to the ease of using the medium but also to the product's ability to create a learning experience that is engaging, focused, and tailored to students' needs.

This high level of practicality is supported by the integration of technology, the cognitive conflict model, and interactive design applied within the game. The cognitive conflict approach is systematically designed through four learning stages, namely: (1) activation of preconceptions and misconceptions; (2) presentation of cognitive conflict; (3) discovery of concepts and equations; and (4) reflection, thereby not only providing an engaging learning experience but also encouraging students to review and reconstruct their conceptual understanding independently.

The results of this study align with previous research [16], which showed that instructional materials using the cognitive conflict approach have a high level of practicality and can facilitate students in independently constructing conceptual understanding. This similarity indicates that the cognitive conflict approach can be packaged in media formats that not only support the concept-construction process but also provide a user-friendly and engaging learning experience for students.

However, the practicality test was conducted only in a one-on-one setting with three students representing high, moderate, and low ability levels. The limited number of subjects does not yet reflect the responses of students with more diverse characteristics. Furthermore, the study has not yet progressed to the small-group and field-test phases, so the practicality of the game in broader classroom learning settings remains unknown. Therefore, future research is recommended to conduct testing on larger and more diverse groups to obtain a more comprehensive picture of the game's application in learning.

Overall, the cognitive conflict-based physics educational game developed in this study demonstrates excellent practicality. This practicality is supported by its ease of use, appeal, systematic presentation, and the integration of the cognitive conflict model into the game's flow. Thus, the game has the potential to be used as an interactive teaching tool that can support student engagement and a concept-oriented physics learning process.

IV. CONCLUSION

Based on the research, the cognitive conflict-based physics educational game on the topics of temperature and heat can be used in the classroom as an interactive teaching tool. The results show that the validity of the cognitive conflict-based physics educational game on the topics of temperature and heat has a value of 0.94, falling into the "highly valid" category, while the practicality of the game has a value of 93.66, falling into the "highly practical" category. This study shows that the developed educational game demonstrates high validity and practicality, thus having the potential to serve as interactive teaching material for the topics of temperature and heat. Therefore, physics educational games can function as teaching materials in physics instruction that are effective in improving students' conceptual understanding.

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