The Effectiveness of Smartphone-Based Interactive Multimedia Integrated Cognitive Conflict Models to Improve 21st-Century Skills

Fatni Mufit*, Yeka Hendriyani, Usmeldi, Muhammad Dhanil, and Mardia Roza Tanjung

***Abstract*—This research aims to develop cognitive conflict-based interactive multimedia that is valid, practical, and effective in improving students' 21st-century skills, known as 4C skills. The development used the Plomp model, with 3 stages: preliminary research, prototyping/development phase, and assessment phase. In preliminary research, teacher questionnaires were used to discover school problems. In the development phase, interactive multimedia prototypes were designed as solutions. At this stage, a validity test was also carried out on the prototype through an expert review by 5 validators. Practicality tests were also carried out through one-to-one and small-group evaluations of 12 students. The instrument of validity and practicality sheets was used at this stage. Experimental research carried out the effectiveness test in the assessment phase 2 sample classes comprising 56 high school students. The 4C skill observation sheet instrument (critical thinking, creativity and innovation, collaboration, and communication) was used at this stage. The data were analyzed by percentage techniques, V-Aiken, N-Gain, and Mann-Whitney tests. The preliminary research results obtained some problems, including low 4C skills, teacher-centered dominant learning, and minimal use of electronic learning media. Interactive multimedia prototypes were designed as solutions. The prototype validity test results were obtained with valid categories. The results of the practicality test at the one-to-one stage and the small group stage obtained scores of 99.2 and 99.4, respectively which are in the very practical category. The results of the effectiveness test based on the N-Gain value inform the improvement of critical thinking skills, and creative thinking is in the high category, while communication and collaboration skills are in the moderate category. Based on the Mann-Whitney U test on all four skills, Sig. (2-tailed) < 0.05 was obtained, which showed a significant effect. In conclusion, cognitive conflict-based interactive multimedia can effectively improve students' 4C skills.**

***Index Terms*—Interactive multimedia, smartphone, cognitive conflict, 21st-century skills**

I. Introduction

Physics is a branch of science that studies natural phenomena, inseparable from observation and experimentation. Learning physics becomes ideal through experimental activities in observing and proving natural phenomena [1]. Student concept mastery can be formed through research through experimental activities [2]. The experimental activities in physics learning aim to create student-centred learning.

Student-centered learning aims to shape 21st-century skills. 21st-century skills are basic skills that everyone must have to be competitive globally [3]. The 21st-century skills consist of critical thinking, creative, communicative, and collaborative skills [4, 5]. Critical thinking is needed in evaluating, choosing, and deciding solutions to a problem in learning [6]. Efforts to generate new and unique ideas in solving a problem can be done through creative thinking. Experimental activities will become more effective through teamwork or collaboration [7]. The ability to convey ideas in writing and speaking is evidence of the results of the activities carried out in learning.

Based on the results of questionnaires obtained from 3 teachers of public senior high schools in Padang, data related to problems in learning were found during COVID-19 pandemic. As many as 87% of the learning process was still teacher-centered through direct learning, 80% of the learning process was dominated by discussing questions and lacking in constructing concepts, 73% of the learning focused on printed teaching materials, and less available interactive electronic teaching materials in supporting online learning during COVID-19 pandemic and the poor understanding of students' concepts and 4C skills in static fluid learning. A large percentage of these problems impact the process of students' concepts and understanding of the material of static fluid. Teacher-centered learning is a problem in learning physics where it is difficult for students to understand concepts; hence misconceptions occur [8]. In addition, learning that focuses on delivering theory only, that is teacher-centered, and without experimentation is one of the inhibiting factors for improving 21st-century skills in students [9]. Students' inability to understand the concepts and their low 21st-century skills are often encountered in learning physics. Misconceptions often occur in static fluid material [10, 11]. In supporting the process of improving 21st-century skills, teaching materials or technology-based learning media are needed in learning [12].

Technology-based teaching materials and media have been widely developed and used in learning. Interactive teaching materials are designed to encourage students' creativity and critical thinking [13, 14, 15]. The use of technology in learning is part of efforts to improve 21st-century skills [16, 17]. Electronic teaching materials developed with simulation presentations provide new experiences for students in improving concepts comprehension and increasing the ability to think more deeply [18, 19]. In addition, using smartphones that provide teaching material applications has been proven to

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Fatni Mufit, Muhammad Dhanil, and Mardia Roza Tanjung are with the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Padang, Indonesia.

Yeka Hendriyani and Usmeldi are with the Electrical Engineering Department, Universitas Negeri Padang, Padang, Indonesia.

*Correspondence: fatni_mufit@fmipa.unp.ac.id (F.M.)

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provide convenience and improve students' 21st-century skills [20]. Interactive multimedia is developed based on the four syntaxes of a cognitive conflict-based learning model designed to train 21st-century skills and improve conceptual understanding.

The cognitive conflict-based learning model (CCBL) is a model of learning based on inquiry and finding solutions to problems. The cognitive conflict-based learning model is one of the models specifically designed to remediate students' misconceptions and improve students' thinking skills [21]. The cognitive conflict-based learning model consists of 4 syntaxes, namely (1) Activation of preconceptions and misconceptions, (2) Presentation of cognitive conflict, (3) Discovery of concepts and equations, (4) Reflection [22]. The advantage of the cognitive conflict-based learning model is the presentation of problems solved through investigation and discovery of concepts from experimental activities. The four syntax models facilitate students to think deeply and to express and restructure their ideas so that their critical and creative thinking, collaborative, and communication skills are built into learning [23]. Cognitive conflict-based learning models can be applied in interactive multimedia teaching materials to make the learning presented more interesting [3].

The use of smartphones in learning is an effort to utilize technology according to the characteristics of 21st-century students. Every high school student has a smartphone and is familiar with using it. Some research shows the positive impact of using smartphones on students in learning. The intensity of smartphone use has significantly influenced students' higher-order thinking skills in physics learning [24]. Virtual physics laboratory applications using Android smartphones can also improve students' understanding of concepts and independent learning [25]. It was also found that experimental smartphone exercises can influence students' understanding of concepts and motivation in learning [26].

Interactive multimedia in this study used the Adobe Animate CC application and integrated virtual static fluid laboratory experiments. The Adobe Animate CC application is very supportive for use on student smartphones [27]. The interactive multimedia integrated the syntax of this study's cognitive conflict learning model. In the interactive multimedia, there was a virtual laboratory and feedback for students from each activity carried out. The stages presented in interactive multimedia aim to improve students' 21st-century skills. Therefore, this study aimed to look at the effectiveness of using cognitive conflict-based interactive multimedia in improving students' 21st-century skills on static fluid material. This study aims to develop interactive multimedia based on cognitive conflicts that are valid, practical, and effective in improving 21st-century skills.

II. Methodology

A. Type of Research

This research uses design/development research using the Plomp model to produce valid, practical, and effective products. The steps of the Plomp development model are 1) preliminary research, 2) prototyping/development phase, and 3) assessment phase, as shown in Fig. 1.

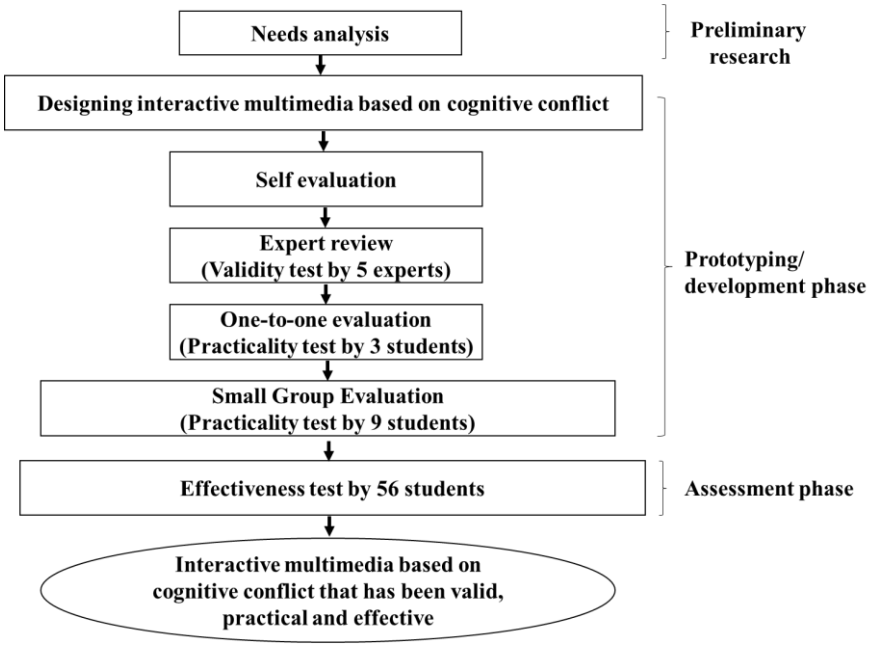

Fig. 1. The procedure of the research.

Fig. 1 shows the research procedure through the 3 stages of Plomp development. In the preliminary research, a needs analysis of teacher needs and student 4C skills was carried out. The research instrument at this stage was a teacher questionnaire to discover school learning problems during the COVID-19 pandemic. Question indicators included the use of learning models and methods, the use of media and learning materials, and several learning activities in the classroom. The 21st-century skills of the students were also revealed through the 4C skills observation sheet, which consisted of indicators of critical thinking skills, creativity, communication, and collaboration.

In the prototyping/development phase, interactive multimedia design was carried out to produce a prototype. Self-evaluation was carried out on the prototype to check the completeness of the material, layout, and button function.

Furthermore, a validity test was conducted through an expert review involving five experts to assess the interactive multimedia. After the product was declared valid by the experts, a one-to-one practicality test was carried out on three students, and after that, revisions were made. Then, the practicality test involving nine students through the small group stage was redone. The research instrument at this stage was a validation sheet consisting of 4 indicators: material substance, learning design, visual communication display, and software utilization (Appendix Table AI). The practicality sheet instrument consisted of 4 indicators: ease of use, attractiveness, efficiency, and benefits (Appendix Table AII). In the validity test, the interactive multimedia prototype was given to the validators to assess the 4 indicators by filling in the validity sheet. Each student was given an interactive multimedia prototype in the one-to-one practicality test. They ran and studied it before the researchers while providing feedback by completing a practical sheet. At the small group evaluation stage, 3 groups of students engaged in the learning process using interactive multimedia prototypes with the researchers as teachers. Then they gave their responses by filling out the practical sheet.

The last stage was the assessment phase to determine the effectiveness of cognitive conflict-based interactive multimedia in improving students' 4C skills. The schools used in this study had the same characteristics. Effectiveness testing was done through quasi-experiment research with the control group pretest-posttest design. The population of this study amounted to 122 students consisting of 4 classes of XI science senior high schools in Kinali, West Sumatra, Indonesia. Two sample classes (experiment and control) were selected through a random cluster sampling technique totaling 56 students. Table I shows the design of the experimental research.

TABLE I: THE EXPERIMENTAL RESEARCH DESIGN

Sample Class	Number	Pretest	Treatment	Posttest
Experiment	28 students (Science 1)	Q1	X	Q2
Control	28 students (Science 2)	Q2		Q2

Q1 = Pretest activity
Q2 = Posttest activity
X = Learning process using interactive multimedia

The experimental class was given the treatment by using interactive multimedia based on cognitive conflict by applying the cognitive conflict-based learning model (CCBL model). In the control class, the learning process used printed teaching materials from publishers by applying the direct instructional model usually implemented in schools. The assessment of 21st-century skills in both classes included the assessment of critical thinking, creative thinking, communication, and collaboration skills using observation sheet instruments for each student (Appendix Table III).

B. Data Analysis Technique

Data on preliminary research were analyzed using percentage techniques. At the development stage, validity data is analyzed using Eq. (1).

$$V=\frac{\sum \text{Score From Expert-The Lowest Scorein Category}}{\text{Number of Category(Number of Expert-1)}} \quad (1)$$

The assessment calculations' results, then, were interpreted based on the Aiken index with the category of validity values $V < 0.4$ (low) and $0.4 \leq V \leq 0.8$ (moderate), and $V > 0.8$ (high) [28]. The practicality test assessment data analysis used a Likert scale and was calculated to determine the final value data from the practicality results using Eq. (2).

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

The practicality assessment results were grouped into 5 categories, namely $0 \leq P \leq 20$ (not practical), $21 \leq P \leq 40$ (less practical), $41 \leq P \leq 60$ (quite practical,) $61 \leq P \leq 80$ (practical), and $81 \leq P \leq 100$ (very practical). In the assessment phase, the increase in students' 21st-century skills is calculated using the N-Gain as in Eq. (3).

$$\langle g \rangle = \frac{\langle S_{post} \rangle - \langle S_{pre} \rangle}{100\% - \langle S_{pre} \rangle} \quad (3)$$

The obtained average N-Gain value was then interpreted based on Table II.

TABLE II: N-GAINS [29]

N-Gains	Category
$g < 0.3$	Low
$0.3 \leq g \leq 0.7$	Moderate
$g > 0.7$	High

The null hypothesis of the product effectiveness test proposed in the study was that there was no significant difference in the use of cognitive conflict-based interactive multimedia in improving 21st-century skills in physics lessons. The tests were the normality test and the Mann-Whitney non-parametric test using SPSS 26. The significance level used was 0.05 or 5%. If the value of Sig. (2-tailed) < 0.05, then the null hypothesis was rejected.

III. RESULT

A. Preliminary Research

Data at the preliminary research stage were obtained through teachers' questionnaires related to the learning process, the availability of media or teaching materials, and students' 21st-century skills. The data showed some existing problems: teacher-centered learning, materials delivery-dominated learning, non-conducive learning conditions during the COVID-19 period, and limited availability of electronic learning media. In addition, there was a poor understanding of students' 4C concepts and skills in static fluid learning. The results of the teacher questionnaires are shown in Fig. 2, and the initial identification of students' 4C skills is shown in Fig. 3.

Fig. 3 shows the percentage value of students' creative thinking at 43.5%, critical thinking at 40.6%, collaborative at

43.5%, and communicative skills at 43.5%. The results identify students' 4C skills as being in a low category.

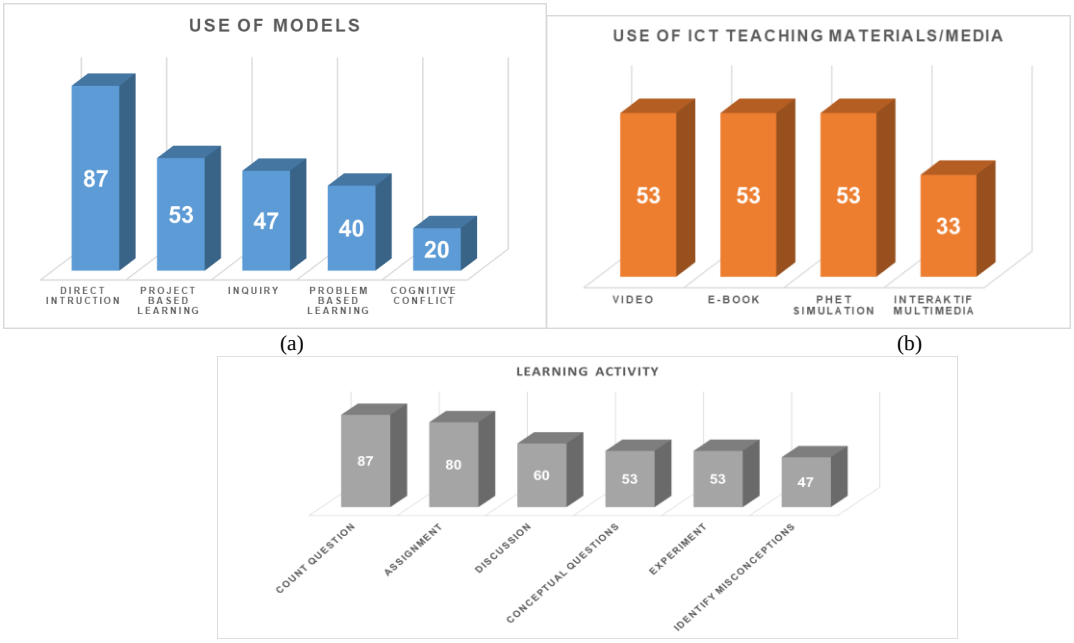

Fig. 2. The results of teachers questionnaires: (a) Use of teaching models; (b) Use ICT teaching materials; (c) Learning activity.

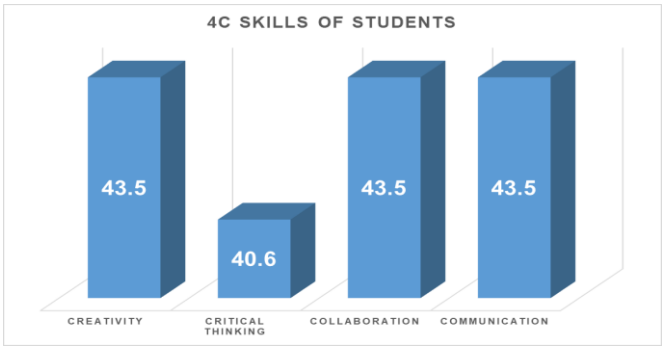

Fig. 3. Early identification of 4C skills.

B. *Development Phase*

Based on the initial research data, interactive multimedia based on cognitive conflict was designed. These interactive multimedia is designed using the Adobe Animate CC application. Text, image, video, and sound materials are arranged proportionally according to the design of the interactive multimedia that has been designed. The resulting interactive multimedia form is developed in Android application format. The form of an interactive multimedia prototype display on a smartphone is presented in Fig. 4.

In the activation stage of preconceptions and misconceptions, students choose answers from statements presented in multimedia to check students' initial understanding and critical thinking skills (See Fig. 4(a)). In the next stage. Students enter the stage of presenting cognitive conflicts where answers are presented in the form of writing hypotheses of the phenomena presented (see Fig. 4(b)). This hypothesis is investigated by discovering concepts and equations through a virtual laboratory (See Fig. 4(c)). The experimental data are presented in the data table (See Fig. 4(d)). Discovery of concepts and equations are carried out through analysis of data results in experimental activities by compiling static fluid equations and concepts (See Fig. 4(e)).

Students analyzed the data results to train students to communicate and collaborate with other members in reporting the results of static fluid experiments on smartphones and group presentations. In the reflection stage, students conduct group discussions, draw conclusions, and conduct exercises related to finding concepts and equations through smartphones (See Fig. 4(f)).

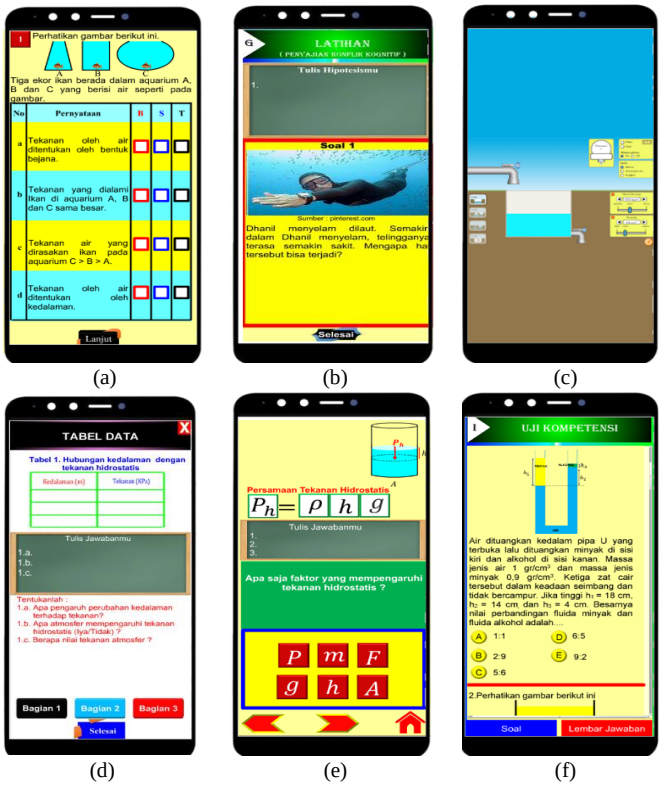

Fig. 4. Interactive multimedia based on cognitive conflict: (a) Activation of preconceptions and misconceptions; (b) Presentation of cognitive conflict; (c) Virtual laboratory; (d) Table Data; (e) Discovery of concepts and equations; (f).Reflection.

After the multimedia was designed and self-evaluated, the product was then followed by a validity test by 5 experts. The results of the validity test are shown in Table III.

TABLE III: VALIDITY TEST RESULTS

Indicators	Score (Category)
Material Substance	0.86 (Valid)
Learning Design	0.87 (Valid)
Visual Communication Display	0.86 (Valid)
Software Utilization	0.87 (Valid)
Average	0.865 (Valid)

TABLE IV: PRACTICALITY TEST RESULTS

Indicators	Scores (one-to-one)	Scores (small group)
Ease of Use	98.38	94.2
Attractiveness	100	90
efficiency	100	95.5
Benefit	100	90
Average	99.2	92.4
Category	Very Practical	Very Practical

The validity test results showed that the product that had been developed had a valid value on all assessment indicators with an average value of 0.865. Suggestions and comments from experts were used as input in revising the product to make it even better. The process continued into the practicality test stage after the product was considered valid and revised. The practicality test was carried out in the one-to-one stage involving 3 students, and then it was revised and tested again in small classes consisting of 9 students. Practicality test results in the one-to-one and small group stages are shown in Table IV.

Table IV shows that the results of the practicality test in the one-to-one stage had an average value of 99.2 with the category of very practical. Meanwhile, in the small group test, an average value of 92.4 was obtained with the category of very practical. The practicality test results show that interactive multimedia had ease of use, attractiveness, and benefits and was used efficiently in learning so that interactive multimedia could continue into the effectiveness test at the assessment phase.

C. Assessment Phase

The assessment phase is carried out to test the effectiveness of the resulting product. The assessment category of 21st-century skills consisted of critical thinking, creativity, communication, and collaboration skills. The results of the 21st-century skills assessment from the activities before the experiment to the fifth meeting were carried out by observation of student activities during the learning process, as shown in Table V.

Table V shows that the control class and the experimental class experienced an increase during the learning process carried out. However, learning to use interactive multimedia based on cognitive conflict experienced a significant increase. A comparison of Pretest and posttest results was used to see the magnitude of the increase in student skill outcomes during the learning process. The results of the pretest and posttest scores from the control and experimental classes on 21st-century skills are shown in Table VI.

TABLE V: RESULTS OF STUDENTS' 21ST-CENTURY SKILLS

Indicator	Class	Meeting					
		Pre	1	2	3	4	5
Critical Thinking	Control Class	44	60	58	61	60	60.7
	Experiment Class	45.2	65.5	70.2	73.8	79.8	88.1
Creativity	Control Class	42.8	53.6	64.3	65.5	69	69
	Experiment Class	44	60.7	71.4	73.8	76.2	85.7
Communication	Control Class	66.7	69	72.6	70.2	70	72.6
	Experiment Class	67.9	73.8	79.8	83.3	84.5	89.3
Collaboration	Control Class	67.9	71	71.4	70.2	67.9	70.2
	Experiment Class	82.1	85.7	86.9	89.3	90.5	82.1

TABLE VI: N-GAIN 21ST CENTURY SKILLS

Categories	Experimental Group (n=28)		<g>	Categories	Control Group (n=28)		<g>	Categories
	Pretest	Posttest			Pretest	Posttest		
Critical Thinking	45.2	88.1	0.78	High	44.05	60.7	0.30	Moderate
Creativity	44.0	85.7	0.74	High	42.86	69	0.46	Moderate
Communicative	69.7	89.3	0.67	Moderate	66.7	72.6	0.18	Moderate
Collaborative	69.0	90.5	0.69	Moderate	67.9	70.2	0.07	Low

Table VI shows an increase in critical thinking in the experimental class by 0.78 or 78% in the high category and the control class by 0.30 or 30% in the moderate category. Interactive multimedia has a positive effect on improving critical thinking skills [30, 31]. In creativity skills, there was an increase in the experimental class by 0.74 or 74% in the high category and the control class by 0.46 or 46% in the medium category. The use of smartphones in learning shows the effect of increasing students' high-level thinking skills [24]. There was an increase in communication skills in the experimental class by 0.67 or 67% in the high category and the control class by 0.18 or 18% in the low category.

Meanwhile, in collaboration skills, there was an increase in the experimental class by 0.69 or 69% in the high category and the control class by 0.07 or 7% in the low category. These results indicate that using interactive multimedia based on cognitive conflict provides a more significant increase in improving 21st-century skills. The SPSS 26 application was used to perform normality and Mann-Whitney tests. The normality test via Kolmogorov-Smirnov was carried out to

determine the normality of the data and the prerequisite test for determining the next statistical test. The significance level used in testing the normality of the data is 0.05. The data is normally distributed if the significance value is greater than 0.05. The results of the normality test on 21st-century skills are presented in Table VII.

TABLE VII: NORMALITY TEST WITH KOLMOGOROV-SMIRNOV

Categories	Class	Means	Std. Deviation	Statistics	Df	Sig.
Critical Thinking	Control	60.89	16.079	0.434	28	0.000 (Not Normal)
	Experiment	88.21	16.1	0.411	28	0.000 (Not Normal)
Creativity	Control	69.32	12.57	0.466	28	0.000 (Not Normal)
	Experiment	85.86	16.63	0.374	28	0.000 (Not Normal)
Communication	Control	72.82	18.24	0.375	28	0.000 (Not Normal)
	Experiment	89.39	15.69	0.429	28	0.000 (Not Normal)
Collaboration	Control	70.54	10.39	0.526	28	0.000 (Not Normal)
	Experiment	90.57	15.18	0.447	28	0.000 (Not Normal)

Based on the data in Table VII, the significance value of critical thinking, creativity, communication, and collaboration skills was 0.000. The Sig. value < 0.05 indicated that the data for all 21st-century skill categories were not normally distributed. The results of data that were not normally distributed required a non-parametric statistical test in the form of the Mann-Whitney test. The results of the Mann-Whitney test on students' 21st-century skills are shown in Table VIII.

TABLE VIII: MANN-WHITNEY U TEST RESULTS

	Critical Thinking	Creative Thinking	Communication	Collaboration
Mann-Whitney U	124.000	204.000	215.000	154.000
Wilcoxon W	530.000	610.000	621.000	560.000
Z	-4.940	-3.694	-3.294	-4.576
Asymp. Sig. (2-tailed)	0.000	0.000	0.001	0.000

Table VIII shows the value of Sig. (2-tailed) < 0.05 in all categories of 21st-century skills, so the proposed null hypothesis was rejected. So, the use of cognitive conflict-based interactive multimedia was effective in improving 21st-century skills in students. Improving 21st-century skills was influenced by two factors in the learning process: the stages of the cognitive conflict learning model and interactive multimedia. The stages of the cognitive conflict learning model in interactive multimedia influence the learning process.

IV. DISCUSSION

The problems found in the preliminary research are problems that many schools experience in various places. The sudden arrival of the COVID-19 pandemic has led to ineffective learning due to the lack of adequate online learning facilities [32]. The main problem for schools is the lack of electronic media and teaching materials that support online learning, so students' understanding of concepts is low [8]. Almost every student already has a smartphone, but it has not been optimally used as an effective learning medium. The design of cognitive conflict-based interactive multimedia that can be used with students' smartphones is an alternative solution to the problem.

The interactive multimedia produced in this study has been validated in 4 aspects: material substance, learning design, visual communication display, and software utilization. Indication of a product being declared valid has met these criteria [9]. In the aspect of material substance, interactive multimedia is valid because the material of static fluid has been complete and correct, following essential competencies. In interactive multimedia, the syntax stages of the cognitive conflict-based learning model are in the substance of the learning design [11]. A proportional layout and well-functioning navigation indicate that interactive multimedia meet the assessment criteria. The proportional display arouses interest in using it [33, 34]. In addition, good software utilization can provide feedback to users, and the resulting product is original work so that it is declared valid [35].

Interactive multimedia in this study is already practical regarding ease of use, attractiveness, efficiency, and benefit. Practicality assessment aims to measure multimedia's appeal, convenience, efficiency, and usefulness for students in learning [27]. Interactive multimedia has an average score of very practical through one-to-one and small-group tests. An attractive display of a product motivates students' interest in learning [12, 24]. Multimedia products in the form of Android applications have a practical indication when all buttons and commands function well and are easy to use by students [11, 14]. Interactive multimedia based on cognitive conflict is suggested to be easy to use by students with very practical results. In addition, cost and time efficiency are essential parts of the practicality of interactive multimedia [36, 37].

The products that have been valid and practical are then implemented in learning to measure the level of effectiveness. Learning using interactive multimedia focuses on the syntax stages in each learning process and the improvement of students' abilities. All components of the syntax of the cognitive conflict-based learning model in the learning process play essential roles in teaching 21st-century skills.

The cognitive conflict-based learning model consists of activating preconceptions and misconceptions, presenting cognitive conflicts, and reflecting stages [23].

First, the activation of preconceptions and misconceptions in interactive multimedia is an activity to activate students' abilities through presenting fact-based questions about physical phenomena that occur in everyday life. Presenting problems presented in interactive multimedia raises students' curiosity in learning [38]. Students' curiosity in learning will train students' critical thinking skills through the use of interactive multimedia [14, 39, 40, 41].

Second, the presentation of cognitive conflict in interactive multimedia seeks to create conflicts in students' minds to find new ideas and solutions to a problem by exhibiting contradictory physical phenomena. Critical and creative thinking is a solution to solve a complex problem [42]. Interactive multimedia helps train students to think creatively through experimental activities and feedback from the media [31, 43].

Third, the discovery of concepts and equations is a stage that seeks to activate all 21st-century skills. The availability of a virtual laboratory allows each student to conduct experiments via smartphone so that all students get the same experience [25, 26]. Finding concepts and similarities encourages students to think deeply [44], collaborate with others, and write answers in interactive multimedia [45]. The use of Android-based multimedia makes it easier for students to explore knowledge and improve skills [46−48].

Fourth, reflection is the stage of re-checking all students' understanding through the percentage of the results of experimental activities. Presentation activities train students to communicate orally and collaborate with group friends in reporting experiment findings. Checking individual understanding in reflection is also carried out through administering students' conceptual understanding tests as feedback to the teacher on student understanding of the learning that has taken place [21, 49].

Each stage in cognitive conflict-based interactive multimedia has a greater effect in enhancing 21st-century skills during learning. This skill increase is supported by the syntax stages of a cognitive conflict-based learning model that presents problems to discover concepts and physics equations through experimental activities. In addition, interactive multimedia provides cost savings, ease of use, distribution, and direct student feedback.

V. Conclusion

In preliminary research, there are learning problems during the COVID-19 pandemic. The problems occurred in the form of teacher-centered learning, materials, no interactive multimedia available and not conducive to learning during COVID-19. At the development stages of interactive multimedia products, the results of validity and practicality assessments obtained were in the valid and practical categories. The assessment phases showed that the use of interactive multimedia during the learning process had improved students' ability on critical thinking, creativity, communication, and collaboration skills. Interactive multimedia based on cognitive conflict is valid, practical, and effective in improving 21st-century skills.

Multimedia was valid regarding material substance, learning design, visual communication display, and software utilization. Multimedia was practical in ease of use, data interest, benefits, and efficiency. Interactive multimedia based on cognitive conflict improved 21st-century skills, namely critical thinking, creativity, collaboration, and communication.

Appendix

TABLE AI: Indicators of Validity

Category	Indicator
Material substance	Presentation of material according to competencies
	Material substance is accurate, complete, and following the development of science
	Symbols, concepts, and physics terms are correct
	Images, videos, and animations according to the material
	Writing style and language are easy to understand
Learning design	The title describes the material
	Indicators and objectives are by the achievement of competencies
	The syntax of the cognitive conflict model is presented systematically and completely
	The activation of preconceptions and misconceptions stage can reveal students' knowledge
	The stage of presenting cognitive conflicts can trigger critical thinking and deep thinking
	The concept and equation discovery stage can trigger students' creative and collaborative thinking.
	The reflection stage can trigger communication skills and reveal students' progress
	Virtual laboratory integration by learning achievements
	Question samples, tasks, and tests according to learning outcomes
	Interactive multimedia facilitate students' critical, creative, communicative, and collaborative thinking skills
	Identity and reference are written completely
Visual communication display	The navigation buttons function well
	The size and type of font and color are proportional
	Images, animations, videos, and sound work well
	The instructions are precise and clear.
Software utilization	The product is interactive
	The product provides feedback to users, and it is an original work
	The product can be operated on smartphones as an application

TABLE AII: Indicators of the Practicality of Interactive Multimedia

Category	Indicator of interactive multimedia
Ease of use	The instructions are easy to understand.
	Buttons and navigation menus are easy to use
	The material presented is easy to understand.
	The activation of preconceptions and misconceptions stage is easy to implement.
	The stage of cognitive conflict presentation is easy to implement.
	The stage of concept and equation discovery is easy to implement
	The stage of reflection is easy to implement.
	Virtual laboratory experiments are easy to do
Attractiveness	The cover display is attractive
	The content display is attractive
	Types of fonts on interactive multimedia are interesting.
	Illustrations and videos are interesting
Efficiency	Interactive multimedia streamlines effective learning time
	Interactive multimedia saves the cost of owning and

	using it.
Benefit	Interactive multimedia can be used for independent learning Interactive multimedia makes it easy to grasp the concepts

TABLE III: INDICATORS OF 21ST-CENTURY SKILLS [9]

Category	Indicator
Creativity	Describe ideas clearly Convey original ideas Provide various interpretations of a problem Dig up information from various sources as a reference to solve the problem
Critical thinking	Evaluate the arguments presented by others Understand how to apply knowledge from situation to situation Understand the questions others have asked Ask questions until other people understand the meaning of the questions given
Collaboration	Helping groups solve problems Provide useful feedback to team members Acknowledge and respect the opinions of group members Be polite and kind to teammates Able to consult in groups for decision making Use time efficiently Discuss completing assignments
Communication	Use spoken and written language according to the content and context of the conversation Speak clearly and easily understood by others Present all information, concisely, and logically Use appropriate body language during presentations Answer questions clearly and briefly

CONFLICT OF INTERESTS

We declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

Fatni Mufit designed and managed the overall research: determining research topics, formulating problems, analyzing, and interpreting data. Yeka Hendriyani designed the interactive multimedia product and validated the instruments of the visual design field and software utilization. Usmeldi partially designed the interactive multimedia and validated the instruments in learning design. Muhammad Dhanil created multimedia prototypes, conducted one-to-one and small-group product trials, and collected and processed the data. Mardia Roza Tanjung conducted the field tests, then collected and processed the data. All authors had approved the final version.

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