Education and Information Technologies (2022) 27:2585–2612
https://doi.org/10.1007/s10639-021-10724-8

Development and evaluation of granular simulation for integrating computational thinking into computational physics courses

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Received: 1 March 2021 / Accepted: 18 August 2021 / Published online: 27 August 2021

Abstract

Computational thinking (CT) is an essential skill in the twenty-first century. The computational physics course (CPC) is one subject that is designed to support students in the practice of CT. Many studies show that the worksheets could be a solution in a CPC as a scaffold to achieve the CT objectives both online and offline. The study aims to develop the worksheet and integrate it with CT in a computational physics course. This study applied the research and development (R & D) method with the ADDIE model approach. In the results, the evaluation test from the experts reached a very good interpretation score based on the learning media expert (96%), the teaching material expert (95%), and the pedagogy experts (92%). So that this media is declared feasible to be used in the CPC. Furthermore, after the experimental study of students who took the computational physics course ($n=31$), the study showed that the modified course could significantly improve student skills regarding overall CT (p value <0.05). However, this research also found that cooperative learning as part of CT had no improvement (p value >0.05). The experiment was conducted amid the COVID 19 pandemic wherein the students could only study at home for the whole semester. These findings indicate that the pandemic has impacted the collaborative skills of students on the course.

Keywords Granular · Physics · Computational thinking · Worksheet

1 Introduction

Computational thinking (CT) stands as an essential twenty-first-century skill (Guggemos, 2020; Voogt et al., 2015; Wing, 2006). CT has a vast spectrum; it has 19 capabilities that are part of CT, e.g., abstraction, algorithm design, visualization,

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and problem-solving (Hsu et al., 2018). Computational physics course is one subject designed to support students to practice CT in higher education, especially in the physics department.

Universities use various methods to teach computational physics; some develop game activities in computer class to increase student motivation (Borrego et al., 2017) and use a gamification experience (Sánchez-carmona et al., 2017) or facilitate an e-Learning (Ngan & Law, 2014). CT in learning aims to train students to be more creative and think logically (Y. Kim & Kim, 2016). The influence of CT in education is far-reaching; many teachers are starting to include it at the level of preschool (Bers et al., 2014; Lin et al., 2020), elementary school (Chalmers, 2018; G. Chen et al., 2017; C. S. Kong & Wang, 2020), and high school level (Guggemos, 2020; Harangus & Kátai, 2020; Zhang & Nouri, 2019). Many of them are even in the form of a formal curriculum that is applied in schools (Bers et al., 2014; Manson & Olsen, 2012; Tang et al., 2020).

The computational course provides practical computation integrated into the scientific problem-solving paradigm in varied knowledge of physics, biology, algebra, and calculus (Borinskaya et al., 2013). A new physics curriculum in which computational education and practice are present would be the best general approach for physics (Landau et al., 2011). CT has important benefits for the teacher in developing ideas to face many difficulties when dealing with physics formulas (Taub et al., 2015) — for example, ranging from the quantum scale in transport phenomena simulation (Ye et al., 2021), the simulation about learning of vector fields as fundamental parts of the electrodynamics course (Budi & Muliyati, 2018), or engineering simulations of physical phenomena (Bakri et al., 2019a), and electromotive forces in a generator (Bakri et al., 2019b). Computation in physics is important for bringing real-world problems into the classroom and making students recognize multiscale challenges (Landau et al., 2011).

According to Landau et al. (2011), students who ran computational simulations in class were probably better than just having the instructor use simulations for demonstrations; the demo method is ineffective for teaching computational physics. In a CPC, the lecture needs to give students a solid foundation in computation and then build computational thinking.

Computational physics plays an important role as a tool to develop and understand fundamental physics and as a guide toward asking more penetrating questions (Prosperetti & Tryggvason, 2003). To reach the stage of understanding, CT in a computational physics course requires strategies and learning media to practice these skills. Several studies using scaffolding have been shown to improve problem-solving abilities (M. C. Kim & Hanna, 2011), collaboration (Huang et al., 2012), digital fabrication (Pitkänen et al., 2020), and computational thinking (Angeli & Valanides, 2020; Basu et al., 2017; Gennari et al., 2016; Touretzky et al., 2013). Scaffolding is also effective in fostering students' group discourse levels and learning outcomes (Huang et al., 2012). In this research, the worksheet uses a scaffolding strategy for learning. Many research on worksheets has been developed in various fields, for example, in physics laboratories (Bakri et al., 2019c), fluid mechanics using computer simulation (Fraser et al., 2007), and simulations in the Direct Current (DC) (Mahtari et al., 2020).

Computational contexts are efficient in physics learning (Redish & Wilson, 1993; Taub et al., 2015). It means that programming simulations can help understand the challenging aspects of physics upon causal relationships between variables. Many simulations have been developed in physics research and education to help CT in physics courses. For example, using a computer simulation environment created in Java for the domain of linear oscillations without damping (Psycharis, 2011) and understanding the vector field using simulation in an Android application (Budi & Muliyati, 2018). Generally, in simulation in physics, the programming process forces the students to understand the physical mechanism activating the simulation (Taub et al., 2015).

Granular is one of the fastest-growing simulations to observe microscopic scale distribution phenomena in physics, e.g., pressure (Matuttis, 1998), and macro view, e.g., waves (Muliyati et al., 2018), or powder and pores (Muliyati et al., 2019). Granular simulations can be applied to almost all physics materials, making them suitable as teaching materials for lectures in computational physics courses. Moreover, granular programming stimulates structured thinking, structured problem solving, and structured information processing (Yao, 2016). In this research. We have developed learning media in a computational physics course to integrate computational thinking skills into the classroom. This worksheet is used as a medium in the classroom using a Granular simulation system to understand computational thinking better.

2 Literature review

2.1 Computational thinking

Computational thinking takes an approach to solve problems, design systems, and understand human behavior that refers to fundamental concepts to computing (Wing, 2006). Thinking like a computer scientist means more than being able to program a computer. It requires thinking at multiple levels of abstraction (Wing, 2006).

Computational thinking promotes new ways of thinking to students across all science disciplines (Atmatzidou & Demetriadis, 2016). This type of thinking will be part of the skillset of other scientists and everyone else. Ubiquitous computing is to today as computational thinking will be to tomorrow. Ubiquitous computing was yesterday's dream that became today's reality; computational thinking is tomorrow's reality (Wing, 2006).

The most important questions that need answering before any serious attempt can be made to introduce curricula for CT development in schools at scale. It is time to redress the gaps and broaden the twenty-first-century academic discourse on computational thinking (Grover & Pea, 2013).

The three dimensions were content knowledge of programming, technological content knowledge of the use of block-based programming environments, and use of the environment to teach programming for CT development with appropriate contextual pedagogy (S. Kong et al., 2020). This article frames the current state of discourse on computational thinking in K–12 education by examining mostly recently published academic literature using Wing's article as a springboard, identifying research gaps, and articulating priorities for future inquiries (Grover & Pea, 2013). According to Wing (2006), computational thinking thus has the following characteristics; conceptualizing, fundamental, a way humans think complements and combines mathematical and engineering thinking, ideas, and everyone everywhere (Wing, 2006).

Computer science teaches a course called "Ways to Think Like a Computer Scientist" to college freshers, making it available to everyone, not just to computer science majors (Wing, 2006). Computational thinking has three dimensions; computational concept, computational practice, and computational practice (Lin et al., 2020; Lye et al., 2014). CT encompasses the concepts of data representation, decomposition, pattern recognition, abstraction, and algorithmic thinking. Five members of our research group independently categorized the project problems before aggregating the results. All five members were familiar with the principles of CT as well as the CS Unplugged activities used in the projects (Rodriguez et al., 2017). The CT step that would develop is shown in Table 1.

CT can be applied in different subjects across different grade levels, which brings challenges and opportunities (Tang et al., 2020). Teachers need to be systematically prepared in terms of how to design CT learning activities, how to teach CT, how to assess CT, and how to use technologies to teach CT concepts (Angeli & Giannakos, 2020). In this research, the type of question in a worksheet based on Table 2.

Finally, we used all literature sources as the theoretical framework to develop the worksheet to train students in CT. Moreover, we considered all the theoretical frameworks obtained to build courses that had an impact on students.

3 Methodology

This research uses a scaffolding strategy through student worksheets to explore granular simulation in a computational physics course. The research study uses the research and development (R & D) method through the ADDIE (Analyze, Design, Develop, Implement, and Evaluate) model approach. One of the powers of ADDIE, Davis (2013) reveals that ADDIE is one of the most recognized and used instructional system design models. Moreover, the ADDIE model is flexible enough to allow anyone to revisit a step and refine it in each five-step. For this reason, the researchers in this study used the ADDIE model as a framework for the development of student's worksheets.

Education researchers widely use research and development (R & D) to create student worksheets, for example, for improving the students' visual-spatial intelligence and learning outcome (Gani et al., 2017), science process skill through inquiry-based learning model (Yulkifli et al., 2019), and scientific communication skills (Oktasari et al., 2019). In terms of research and development study, many models are commonly used; for example, 4D (Oktasari et al., 2019), Borg & Gall (Khasanah et al., 2017), Dick Carey (Astra et al., 2020; Bakri et al., 2019c), and ADDIE (da Silva et al., 2016; Denny et al., 2020; Majid et al., 2015; Raihanati et al., 2017). Of the many models, the ADDIE model is the most relevant in the

Table 1 A CT Skills model applied in the study (Atmatzidou & Demetriadis, 2016)

CT Step	*Definition*	*Student skills* *(The student should be able to)*
Abstraction	Create a simple formulation from something complicated.	1. Separate the importance from the redundant data. 2. Analyze programming constructions among different programming scripts. 3. Recognize ideas between different software design environments.
Algorithm	Write step-by-step orders for carrying out a procedure.	1. Explicitly state the procedure steps. 2. Classify different applied algorithms for a specified problem. 3. Discover the most effective procedure.
Generalization	Transfer a problem-solving process to varied difficulties	Expand a present solution to cover more possibilities.

Table 2 CT skills and relevant prompts to trigger students' self-reflection (Atmatzidou & Demetriadis, 2016)

CT skills	*Type of Question*
Abstraction	How would you describe this common behavior? What is the common programming structure? Which is the information you actually need? What is irrelevant detail and not necessary in your description?
Algorithm	Write step-by-step the operations needed so that you can do what the problem asks. What are the steps I will need to do to solve this problem?
Generalization	Propose a more general solution for the activity above that can cover a wider variety of cases. Is the proposed solution more general, and why?

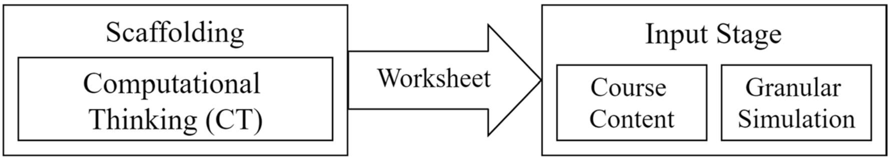


Fig. 1 Incorporating CT into a worksheet

application of this research. Many researchers apply the ADDIE model to develop Educational products such as to develop a virtual learning environment (da Silva et al., 2016), mobile learning (Shah et al., 2019; Sulisworo et al., 2016), and textbooks integrated with augmented reality (Mustami et al., 2019). The educational philosophy for this application of ADDIE is that intentional learning should be student-centered, innovative, authentic, and inspirational (Branch, 2010).

In the first phase, analysis, we conducted learning analysis in a CPC class, such as the target audience of this development (i.e., undergraduate students of physics), education objective (i.e., computational thinking), and the available resources (i.e., online learning).

In the design stage, the content was organized, and we collected analytical data and grouped the problems obtained into a flowchart. Moreover, the result of design, the CT in the CPC, needed to support using a scaffolding strategy through student's worksheet. A diagram of this concept is shown in Fig. 1.

The scaffolding strategy provides the learning framework to help the students learn the new knowledge (Hsu et al., 2018). The purpose of scaffolding is to train the students to solve problems independently (Hsu et al., 2018). Researchers emphasize the importance of providing additional support or scaffolding to facilitate learners' cognitive development during the learning process (W. Chen et al., 2010; Huang et al., 2012; Wood et al., 1976). Korkmaz et al. (2017) said that computational thinking covers the skills of critical thinking, creativity, cooperativity, algorithmic thinking, and problem-solving. In this research, the worksheet uses three steps of CT: abstracting, algorithm, and generalizing. The diagram about an illustration of worksheet design is shown in Fig. 2.

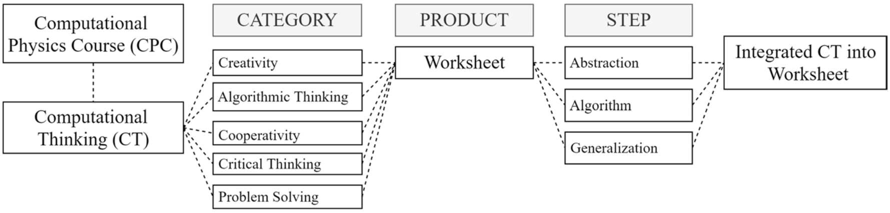


Fig. 2 Schematic illustration of worksheet design

The researcher decided to use three dimensions of CT in developing a worksheet as scaffolding in the computational course and five categories of CT provided in the step of the worksheet. The result of this development is the integrated CT in a worksheet in the computational physics course.

In the development stage, we created simulations using Unity3D and involved programming using Visual Studio 2017. Google Drive was also used to store the executable simulation for Windows 10; then, students can download it via a browser at https://osf.io/wcyqn/.

In the implementation stage, the pre- and post-test[1] using Google Form were made available on an educational platform, allowing access through the internet. The student's worksheet can be accessed from our data repository at https://osf.io/5tehf/.

The evaluation of the student's worksheet was carried out by three experts with experience in learning media, teaching material, and pedagogy to verify the adequacy of the content and strategies used for the learning process of the target audience.

After developing the learning media, we implemented the worksheet in a case experiment study. This case experiment uses a quasi-experimental design with a pre-test and post-test approach. The respondents consisted of undergraduate students in physics at the State University of Jakarta (Universitas Negeri Jakarta) who attended the computational physics course. Based on the survey, it was found that there were only 62 students registered for the subject during the course of study, consisting of a physics education class ($n=31$) and a physics class ($n=34$). We decided to use the former class as an experiment class and the latter as a class to test the reliability of the questionnaire item. All participants in the research were purely voluntary and understood how they were to be engaged. The participants' data was anonymized and kept confidential in the research.

The questionnaire to measure CT skills used in this study was adapted from the questionnaire designed by Korkmaz et al. (2017). The questionnaire served as an instrument to obtain CT scores before and after intervention consisting of creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. Five-point Likert was used in the expert evaluation and CT scale. The scale ranges from strongly disagrees (1), disagree (2), neutral (3), agree (4), and strongly agree (5).

[1] https://s.id/ct-posttest

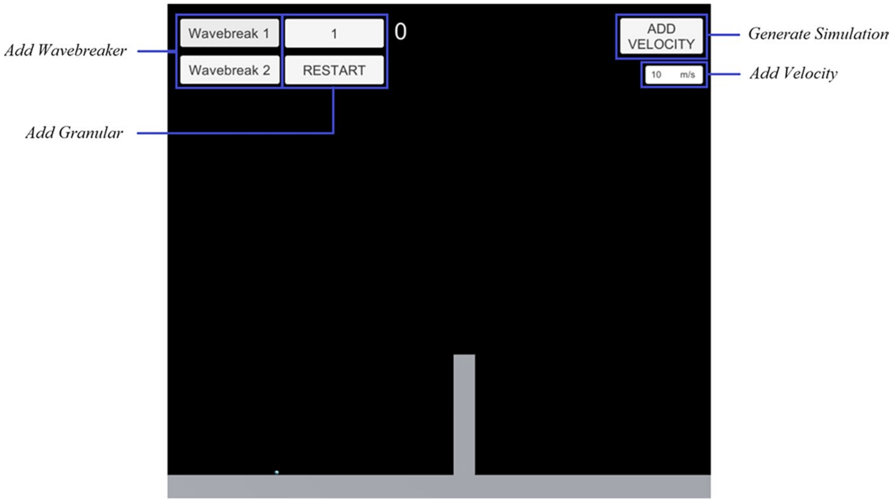


Fig. 3 The Component of Simulation

4 Result and discussion

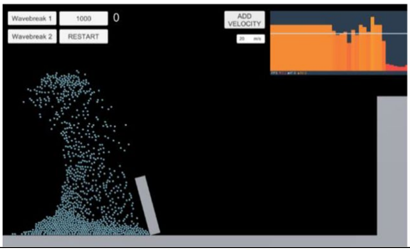
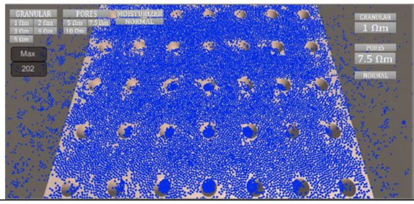
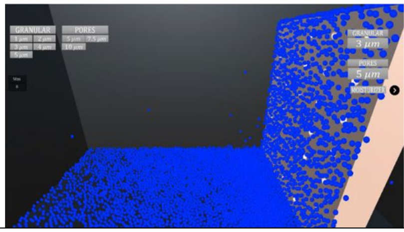
4.1 Application

Applications were created using the Unity3D application and Visual Studio 2017 coded in C# applications made to follow the three golden rules to design User Interface (UI) that consist of user control, memory load, and consistency (Bahrami & Bahrami, 2012). This application also uses an interactive interface to motivate the student (Malkawi et al., 2019). Technically, there are various buttons that users could press to activate certain functions, such as the Wavebreak button (Fig. 3) to bring up a wall for breaking waves.

In this study, three simulations were used, namely Wavebreaker Simulation, simulation of granular adhesion to horizontal porous skin, and simulation of granular adhesion to vertical porous skin. The three simulation applications can be seen in Table 3.

Three applications were used on students with different learning objectives. In the three applications, the general objective is to develop CT in students in formulating a problem and its solutions so that humans and machines can effectively carry it out (Lei et al., 2020; Wing, 2006). Students were also encouraged to describe and organize data with appropriate graphs, charts, words, or images as part of CT (Hsu et al., 2018). For example, the resulting process in the Wavebreak Simulation was observed in increasing a given velocity that affects the reached maximum height particle and convergence of the granular particle movement (Muliyati et al., 2018). In addition, learning aims to describe the complex problems of the application into a description in the form of algorithmic notions of the flow of control (Grover & Pea, 2013).

Table 3 The simulation that used in this study.

Concept and Learning Objective	***Simulation***
Wavebreak Understand the computation system of the granular particle in wave breaker using the rigid body properties	
Horizontal Pore Understand the computation system of the granular attachment in horizontal pore	
Vertical Pore Understand the computation system of the granular attachment in vertical pore	

4.2 Student learning outcomes after using the application

Learning outcomes are important to monitor and to aid good teaching and learning. Learning outcomes are useful as practical tools in teaching and learning activities and in designing study programs (Hussey & Smith, 2010). The learning outcomes can be seen in Table 4.

4.3 Worksheet

Many studies using scaffolding show an improvement in problem-solving abilities (M. C. Kim & Hanna, 2011), collaborative behaviors (Huang et al., 2012), digital fabrication (Pitkänen et al., 2020), and computational thinking (Angeli & Valanides, 2020; Basu et al., 2017; Gennari et al., 2016; Touretzky et al., 2013). Scaffolding is effective in fostering students' group discourse levels and learning outcomes (Huang et al., 2012). Learning practicum using the worksheet as a scaffold also provides students opportunities to find and apply concepts (Bakri et al., 2020). In this research, the worksheet was applied as a scaffolding strategy in the CPC. CT has three dimensions (Lin et al., 2020; Lye et al., 2014), and every dimension was added to every step of the worksheet. The steps of the worksheet are shown in Figs. 4, 5, 6, 7 and 8.

Table 4 Teaching and learning process.

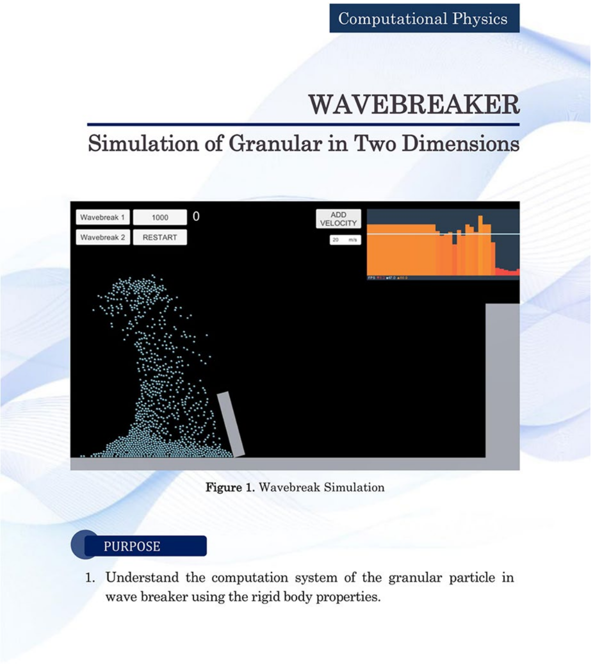
Syntax/Step	***Display***	***Learning Outcomes***
Abstraction		
Find Data	ABSTRACTION 1. Simulate your program based on the Table 1 and fill data in the Table. Tabel 1. The Data from the Simulation Velocity of Wave (m/s) | Pass the Wall (n): 0˚ | 15˚ 2 | ... | ... 10 | ... | ... 18 | ... | ... 22 | ... | ... 26 | ... | ...	Students can create simple data from something complicated in the application.
Behavior	2. How would you describe this common behaviour of program?	Students can define the common behavior of data.
Iteration	3. What is the repeat step in this program? (iteration)	Students can analyze common behaviors or programming structures (iteration).
Output	4. Which is the data you actually need? (The Output)	Students can identify the actual need for data (output).
Revision	5. What is irrelevant detail and not necessary in this program?	Students can identify abstractions between different programming environments.
Algorithm		
Write Step-by-step	ALGORITHM 1. Write step-by-step the operations needed so that can can generate the data!	Students can practice writing step-by-step specific and explicit instructions for carrying out a process.
Draw Step-by-step	2. Draw step-by-step the operations that you write in number 1 (Flowchart). Start	Students can explicitly state the algorithm steps using a flowchart and find the most efficient algorithm.
Generalization		
Propose general simulation	GENERALIZATION 1. Propose a more general solution for the this simulation, that can cover a wider variety of cases!	Students could be transferring a problem-solving process to a wide variety of problems.

The cover (Fig. 4), the first page of worksheet, provides the learning objectives. It is important to identify objectives in the classroom for learners to achieve to stimulate and excite attention (Waiyakoon et al., 2015).

The procedure in the worksheet stage is needed to invite students to understand what to do (Fig. 5). Some lecturers give this stage verbally, although, to support independent learning, worksheets can be added with procedures (Bakri et al., 2020).

Abstracting is a stage for practicing CT (Barr & Stephenson, 2011; Grover & Pea, 2013). This section describes the simulation and process in the system (Fig. 6). Abstraction is the process of creating something simple from something complicated (Atmatzidou & Demetriadis, 2016). In this step, students learned about fundamental programming concepts such as sequences and looping (iteration) as part of computational concepts (Lin et al., 2020; Lye et al., 2014). This step aimed to separate the

Fig. 4 The Purpose page


Computational Physics

WAVEBREAKER

Simulation of Granular in Two Dimensions

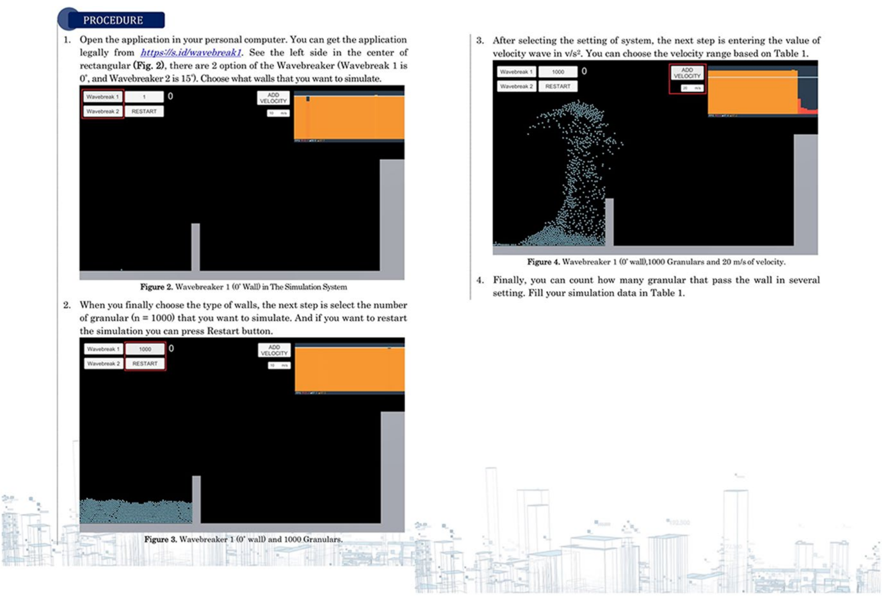
Wavebreak 1 | 1000 | 0 | ADD VELOCITY | 20 m/s

Wavebreak 2 | RESTART

Figure 1. Wavebreak Simulation

PURPOSE

1. Understand the computation system of the granular particle in wave breaker using the rigid body properties.


PROCEDURE

1. Open the application in your personal computer. You can get the application legally from *https://s.id/wavebreak1*. See the left side in the center of rectangular **(Fig. 2)**, there are 2 option of the Wavebreaker (Wavebreak 1 is 0˚, and Wavebreaker 2 is 15˚). Choose what walls that you want to simulate.

Figure 2. Wavebreaker 1 (0˚ Wall) in The Simulation System

2. When you finally choose the type of walls, the next step is select the number of granular (n = 1000) that you want to simulate. And if you want to restart the simulation you can press Restart button.

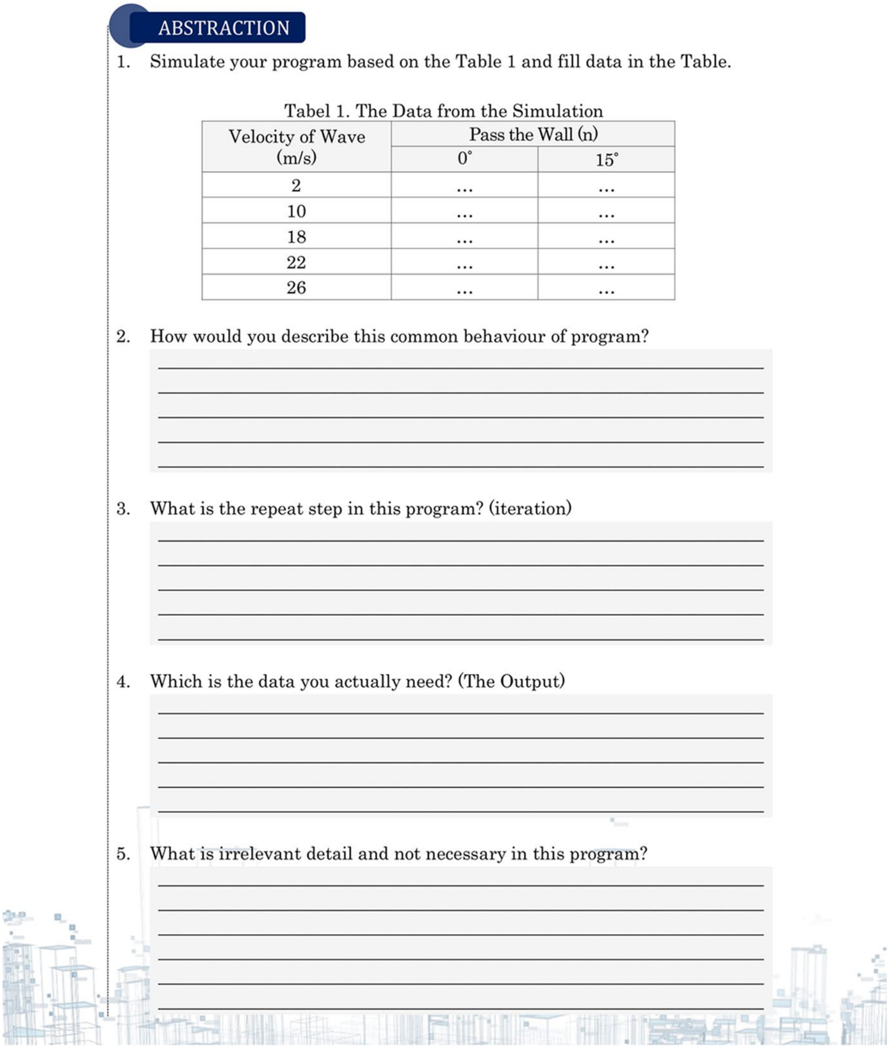
Figure 3. Wavebreaker 1 (0˚ wall) and 1000 Granulars.

3. After selecting the setting of system, the next step is entering the value of velocity wave in v/s². You can choose the velocity range based on Table 1.

Figure 4. Wavebreaker 1 (0˚ wall),1000 Granulars and 20 m/s of velocity.

4. Finally, you can count how many granular that pass the wall in several setting. Fill your simulation data in Table 1.

Fig. 5 Procedure in the worksheet



ABSTRACTION

1. Simulate your program based on the Table 1 and fill data in the Table.

Tabel 1. The Data from the Simulation

Velocity of Wave (m/s)	Pass the Wall (n)	
	0°	15°
2	...	...
10	...	...
18	...	...
22	...	...
26	...	...

2. How would you describe this common behaviour of program?

3. What is the repeat step in this program? (iteration)

4. Which is the data you actually need? (The Output)

5. What is irrelevant detail and not necessary in this program?

Fig. 6 Abstraction step

important from the redundant information, to analyze and specify common behaviors or programming structures between different scripts, and identify abstractions between different programming environments (Atmatzidou & Demetriadis, 2016). This section also includes data collection, data analysis, data representation, and problem decomposition (Y. Kim & Kim, 2016).

At the algorithm stage (Fig. 7), students were given analysis and the stages of drawing a flowchart. Flowcharts are important in shaping CT and triggering students to understand more deeply about how computers work (Barr & Stephenson, 2011; Grover & Pea, 2013; Hsu et al., 2018). The algorithm in this step is a practice of writing step-by-step specific and explicit instructions for carrying out a process

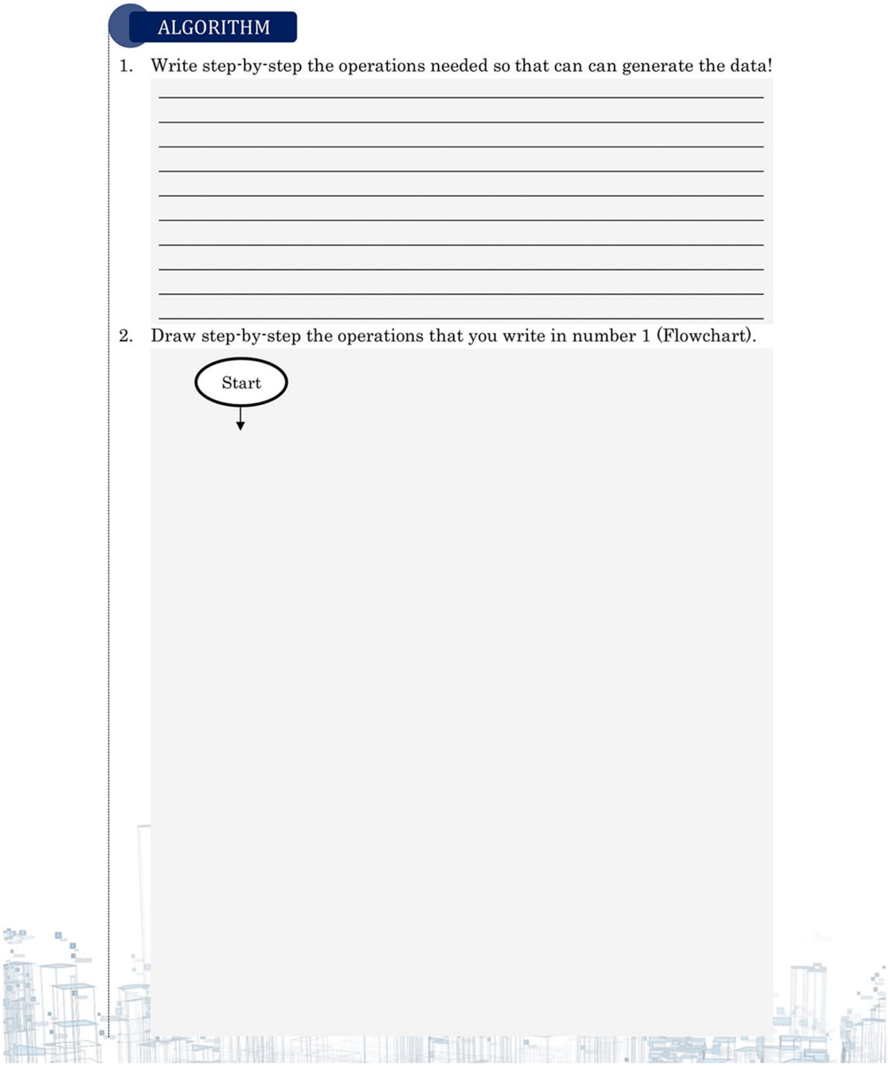


Fig. 7 Algorithm Step

(Atmatzidou & Demetriadis, 2016). The algorithm step aims to explicitly state the algorithm steps, to identify different effective algorithms for a given problem, and to find the most efficient algorithm. In this step, students learn about problem-solving skills such as testing and debugging as part of computational practices (Lin et al., 2020; Lye et al., 2014).

In the generalization stage (Fig. 8), students are encouraged to recognize ideas and apply them in other fields; students can interpolate their ideas into various fields that they work on. This worksheet explains wave breakers, and students can find out for themselves what programs can be developed using a

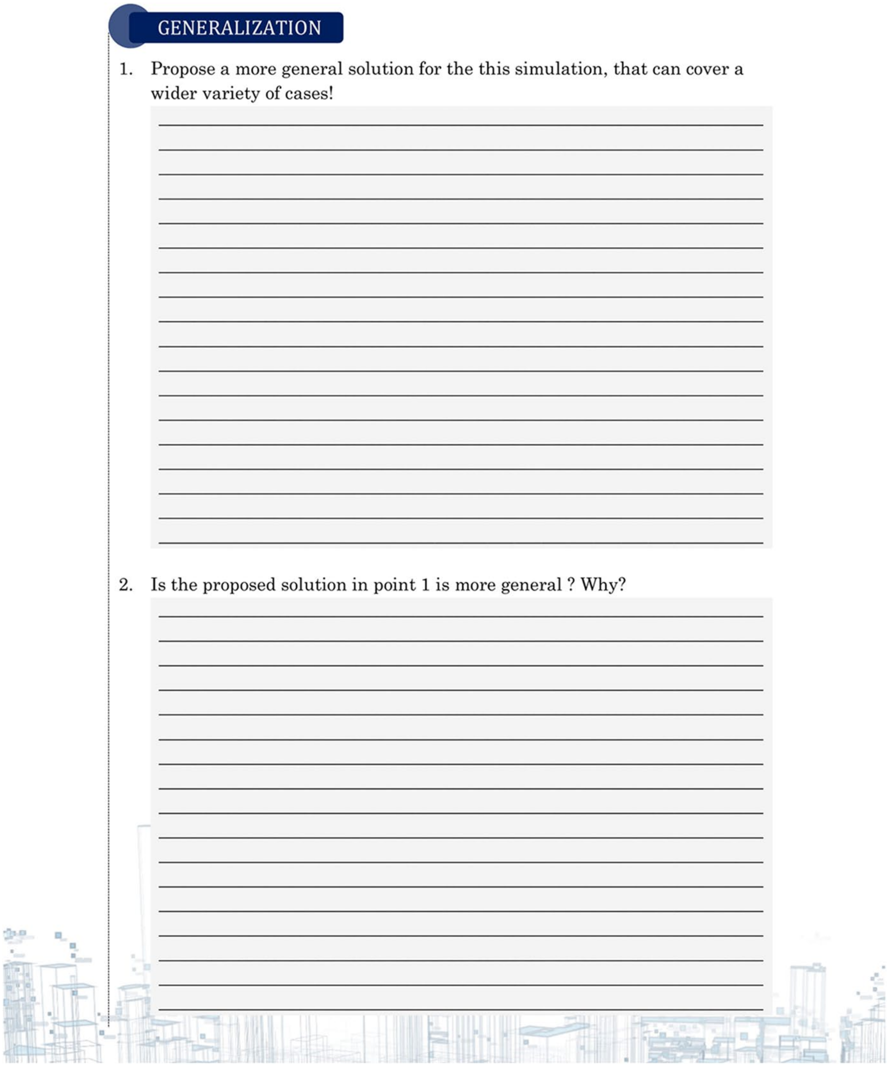


Fig. 8 Generalization Step

CT framework. The generalization is transferring a problem-solving process to a wide variety of problems, expanding an existing solution in a given problem to cover more cases (Atmatzidou & Demetriadis, 2016). In case of questioning, the use of technology is part of computational perspectives. It means that students understand the relationships between themselves and others in a technological context (Lin et al., 2020; Lye et al., 2014).

Table 5 The validation results of the students' worksheet

No.	*Aspects Measured*	*Presentation Score*	*Interpretation*
Learning Media Validation			
1	Worksheet Component	95%	Very Good
2	Typography of contents	97%	Very Good
Average of all aspects		**96%**	**Very Good**
Teaching Material Validation			
1	Material content	97%	Very Good
2	Writing Language	93%	Very Good
Average of all aspects		**95%**	**Very Good**
Pedagogy Expert Validation			
1	Didactic aspect	90%	Very Good
2	Construction aspect	98%	Very Good
3	CT in Worksheet	93%	Very Good
4	Characteristics of CT	98%	Very Good
5	Abstraction	88%	Very Good
6	Algorithmic Thinking	87%	Very Good
7	Generalization	90%	Very Good
Average of all aspects		**92%**	**Very Good**

4.4 Evaluation test

The fifth stage of the ADDIE model is evaluation. The evaluation test used Likert as a sample of evaluation tools (Branch, 2010). The evaluation of the student's worksheet was carried out by three experts with experience in learning media, teaching material, and pedagogy. In the process of evaluation framework, the experts including lecture and schoolteacher who specialize in the study were invited to review and evaluate the model, thus raising the validity of the product. The evaluation results are shown in Table 5.

The results of media validation have obtained very good interpretation (overall 96%). It means that the worksheet component (95%) and typography of contents (97%) were deemed appropriate by experts. The results of the material validation were obtained excellent interpretation (overall 95%). The material presented logical principles in the worksheet in Granular content. From material experts, good material content is gained (97%), and suitable in writing language (93%), e.g., it was easy for the student to know meanings and prevent misconceptions.

The results of learning validation have an average score of 92%. Each component of learning expert validation is suitable in the didactic aspect (90%), e.g., emphasizes students on the process of learning concepts, contains contextual learning, construction aspect (98%), e.g., provide sufficient space to provide flexibility for students to write down their observations on a worksheet, CT in the worksheet (93%), e.g., potentially approach to solving problems, and to understand human behavior, characteristics of CT (98%), e.g., provide a way that humans think, and potentially can develop CT, abstraction (88%), e.g., trigger student to create something simple

Table 6 The grouping of the questionnaire items

Category	Questionnaire Items
1. Creativity	20, 21, 22, 23, 24, 25, 27, 28
2. Algorithmic Thinking	1, 5, 6, 7, 8, 9
3. Cooperativity	14, 15, 16, 17
4. Critical Thinking	10, 11, 12, 13, 29
5. Problem Solving	2, 3, 4, 18, 19, 26

from something complicated, separate, and identify abstractions between different programming environments, algorithmic thinking (87%) i.e., trigger student to practice writing step-by-step, and find the most efficient algorithm, generalization (90%) i.e., trigger student to transferring a problem-solving process, expand more possibilities. In learning expert perception, the critical step in a worksheet to train CT, abstraction, algorithmic thinking, and generalization have shown good interpretation, meaning this worksheet potentially allows students to improve their skills.

4.5 The validity and the reliability

After the media was developed and evaluated, it was tested on classroom activity using a questionnaire developed by Korkmaz et al. (2017) and detailed in Appendix Table 8, to check the students' CT skills before and after the intervention. The validity tests were conducted to test the construct validity of the CT test; the results have been determined as valid using Kaiser-Meyer-Oklin (KMO) = 0.914 and the Bartlett test value $x^2 = 15{,}886.208$ (Korkmaz et al., 2017).

In this research, most of the categories in the questionnaire reach high reliability, but for item 24, reliability was very low; therefore, this item questionnaire was omitted (see Appendix Table 9). After reorganizing, all categories resulted in high reliability (Cronbach's alpha was 0.876 for all categories). In addition, the reliability test using alpha Cronbach in previous research was reliable (Cronbach's alpha 0.822 for all categories) (Korkmaz et al., 2017). The grouping of the questionnaire statements is shown in Table 6.

4.6 Data analysis of student response

In this work, after reorganization based on validity and reliability, we used the questionnaire to analyze student responses via CT. All respondents for this study pursued an undergraduate degree in a computational physics course at the physics department, State University of Jakarta. The data collection was conducted with pre-test and post-test for computational thinking. The questionnaire was used to determine the response of students after using students' worksheets. The data were organized using the spreadsheet in Microsoft Excel 365 and SPSS software.

The intervention consisted of several stages; students used worksheets independently for three topics. The collected data then presented in a paired t-test to see the significance of the intervention (see Appendix Table 10). For data collection,

Table 7 The experimental group results (Physics Education Class)

$N=31$	Average score (pre-test)	Averagescore (post-test)	Difference average (pre-test)	Difference average (post-test)	Paired t-test Significance
Category					
Entire Questionnaire	68.69	70.51	5.47	5.23	$P=0.045$
Creativity	72.47	74.96	6.83	7.45	$P=0.041$
Algorithmic Thinking	61.39	65.69	9.73	8.70	$P=0.014$
Cooperativity	83.54	80.81	12.79	14.03	$P=0.127$
Critical Thinking	66.45	68.64	8.49	7.45	$P=0.045$
Problem Solving	64.09	66.88	6.70	7.29	$P=0.047$

29 main instruments were used in a Likert-type questionnaire. First, the questionnaire was given to students before the intervention as a preliminary test; then, we organized the questionnaire items by category and calculated the average score of all statements in each category for each student. Second, we calculated the average scores of all students for the entire questionnaire. When statistical differences from the pre-test scores between the two situations were found. Finally, we conducted paired t-tests, comparing the mean scores of all students across the questionnaire and each category separately, pre-test and post-test. The paired t-test was used to determine whether the experimental class acquired a higher ability after the intervention.

Table 7 shows that in the experimental group, after the intervention, the statistical analysis of the whole category was significant ($P=0.045$) and marked improvement ($P<0.05$) in students' computational thinking, according to all questionnaires and overall categories, except for the cooperativity category. However, in one category, the cooperative category, there was an anomaly where a high a priori score became a low score in the final session.

From Table 7, creativity category was a significant ($P=0.041$) and marked improvement ($P<0.05$). This category shows that student skills had significant improvement using the learning media, such as trusting their intuition and feelings of "trueness" and "wrongness" when they approach a problem and the belief that they can solve any problems when they encounter a new situation. This condition was supported by the experiment from Dinica et al. (2010) that such experiments in physics using interactive strategies lead to the students' creativity development.

In the algorithmic thinking category, student skill also significantly improved ($P=0.014$; $P<0.05$), the student improvement. This condition is the same as the previous research results that reveal the optimal educational method of developing students' algorithmic thinking is the system and multidisciplinary approach based on the identification of real systems, processes, and modelling (Hubalovsky, 2015).

In critical thinking, the improvement of skill was significant ($P=0.045$, $P<0.05$). This category included the willingness to learn challenging activities, feeling eager to solve complex problems, and using a systematic method when comparing the options while reaching a decision. In this limited condition, critical thinking could still improve. Based on the research from Hussin et al. (2019), critical thinking can be improved either online learning or offline learning; the keyword is interaction. Then, Bakri et al. (2018) and Denny et al. (2020) also reveal that critical thinking can be reached using e-learning or blended learning (Tab 10).

In the problem-solving category, there was a significant ($P = 0.045$; $P < 0.05$) and marked improvement. This category included applying the solution that students plan, demonstrating the solution of a problem, developing their ideas in the environment, and producing so many options while thinking of the possible solution to a problem. In this study, we tried to support students in generalizing the theory from the learning process to other fields. Innovative learning is needed to improve problem-solving abilities in overcoming students' physics problems (Tumanggor et al., 2019).

In the cooperativity category, there was an anomaly where a high a priori score (83.54) became a low score in the final session (average score = 80.81). Because of the decrease of score, the paired t-test (average score = 0.127) was not significant ($p > 0.05$). The items that have not increased include solving problems related to a group project and friends, experiencing cooperative learning together, encouraging ideas in cooperative learning, and attaining successful results in a working group. To explain, this may partly be due to the pandemic, and reliance on independent learning may have placed a burden on cooperative learning skills. From a recent study by Ivone et al. (2020), the previous research reveals to use almost no cooperative learning. Thus, even without the financial and technological obstacles, cooperative learning may not be applied in pandemic conditions. Moreover, the previous research from Farn-Shing Chen et al. (2020) reveals that different cooperative learning methods had significant differences in their achievement in programming design learning. Face-to-face learning was superior to online learning in pandemic situations because of more learning difficulties and problems (F. S. Chen et al., 2020). These findings could become further research related to cooperative approaches in learning topics such as physics and computation in various learning conditions.

5 Conclusions

The worksheet in the computational physics course has been developed in this research. The expert evaluation results inform that the worksheet of computational thinking has met the criteria in terms of teaching material, learning media, and pedagogy so that it is declared very feasible to be used within the computational physics course. Moreover, after the experimental study of students who took the computational physics course ($n = 31$), the results show that the modified course significantly improved student skills regarding overall CT ($p < 0.05$). However, this research also found that cooperative learning as part of CT in the experiment condition had no improvement ($p > 0.05$). Moreover, the experiment was conducted amid the COVID 19 pandemic wherein the students could only study at home during the semester. This finding indicates that the pandemic has had an impact on collaborative skills in students on the CPC.

Appendix 1

Table 8 Questionnaire Instrument

Category	Items	Questionnaire
Creativity	20	I trust my intuitions and feelings of "trueness" and "wrongness" when I approach the solution of a problem
	21	Dreaming causes my most important projects to come to light.
	22	I like the people who are realistic and neutral
	23	I like the people who are sure of most of their decisions
	24	When I encounter with a problem, I stop before proceeding to another subject and think over that problem
	25	I trust that I can apply the plan while making it to solve a problem of mine.
	27	I believe that I can solve most of the problems I face if I have sufficient amount of time and if I show effort
	28	I have a belief that I can solve the problems possible to occur when I encounter with a new situation
Algorithmic thinking	1	I can digitize a mathematical problem expressed verbally.
	5	I can mathematically express the solution ways of the problems I face in the daily life.
	6	I think that I have a special interest in the mathematical processes
	7	I can immediately establish the equity that will give the solution of a problem
	8	I believe that I can easily catch the relation between the figures
	9	I think that I learn better the instructions made with the help of mathematical symbols and concepts
Cooperativity	14	I like solving problems related to group project together with my friends in cooperative learning
	15	I like experiencing cooperative learning together with my group friends
	16	More ideas occur in cooperative learning.
	17	In the cooperative learning, I think that I attain/will attain more successful results because I am working in a group

Table 8 (continued)

Category	Items	Questionnaire
Critical thinking	10	I am willing to learn challenging things.
	11	It is fun to try to solve the complex problems.
	12	I am good at preparing regular plans regarding the solution of the complex problems.
	13	I am proud of being able to think with a great precision.
	29	I make use of a systematic method while comparing the options at my hand and while reaching a decision
Problem solving	2	I cannot apply the solution ways I plan respectively and gradually
	3	I have problems in the issue of where and how I should use the variables such as X and Y in the solution of a problem.
	4	I have problems in the demonstration of the solution of a problem in my mind.
	18	It tires me to try to learn something together with my group friends in cooperative learning.
	19	I cannot develop my own ideas in the environment of cooperative learning.
	26	I cannot produce so many options while thinking of the possible solution ways regarding a problem.

Appendix 2

Table 9 The Reliability of Questionnaire

Item	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
1	102.1290	115.516	.125	.855
2	101.9355	112.129	.237	.854
3	102.0000	111.933	.223	.854
4	102.1935	108.295	.333	.852
5	101.9032	109.090	.419	.849
6	101.9032	102.624	.589	.842
7	102.0968	106.624	.487	.846
8	101.9355	112.529	.213	.854
9	101.6129	107.778	.496	.846
10	101.5806	106.118	.546	.845
11	101.6774	106.026	.590	.844
12	102.0323	111.032	.391	.850
13	101.4839	105.858	.623	.843
14	101.5161	103.858	.609	.842
15	101.3871	104.578	.715	.840
16	101.4194	104.452	.607	.842
17	101.3871	105.445	.623	.843
18	101.7419	109.398	.327	.852
19	101.5806	109.585	.392	.849
20	101.9355	109.796	.305	.852
21	101.5806	112.452	.205	.855
22	100.9677	108.966	.459	.848
23	100.9677	110.632	.378	.850
24	103.0645	127.262	−.573**	.876**
25	101.5806	109.385	.463	.848
26	102.3871	115.978	.018	.859
27	101.1290	114.316	.131	.856
28	101.2903	105.346	.614	.843
29	101.5161	108.058	.475	.847

**Delete due to the low reliable

Appendix 3

Table 10 Score of Experimental Group (Physics Education) ($N=31$)

ID	Overall		Creativity		Algorithmic Thinking		Cooperativity		Critical Thinking		Problem Solving	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
1	65.93	78.52	73.33	80.00	50.00	80.00	80.00	80.00	72.00	80.00	60.00	73.33
2	69.63	68.89	73.33	76.67	56.67	60.00	100.00	90.00	64.00	64.00	63.33	60.00
3	76.30	78.52	80.00	80.00	73.33	80.00	80.00	80.00	80.00	80.00	70.00	73.33
4	69.63	74.07	66.67	63.33	60.00	66.67	100.00	100.00	68.00	72.00	63.33	76.67
5	70.37	78.52	70.00	80.00	60.00	70.00	100.00	100.00	68.00	64.00	63.33	83.33
6	65.93	64.44	60.00	60.00	53.33	60.00	100.00	80.00	60.00	56.00	66.67	70.00
7	64.44	65.93	73.33	63.33	50.00	60.00	85.00	75.00	68.00	64.00	60.00	56.67
8	70.37	74.81	83.33	90.00	70.00	80.00	75.00	80.00	60.00	68.00	60.00	66.67
9	66.67	65.19	73.33	70.00	56.67	53.33	65.00	65.00	60.00	60.00	63.33	63.33
10	65.93	64.44	63.33	73.33	50.00	70.00	80.00	75.00	68.00	68.00	63.33	60.00
11	62.22	71.85	83.33	86.67	60.00	60.00	85.00	85.00	68.00	68.00	56.67	60.00
12	69.63	69.63	83.33	76.67	66.67	70.00	85.00	80.00	52.00	72.00	66.67	63.33
13	77.78	74.07	66.67	80.00	46.67	60.00	100.00	95.00	72.00	68.00	53.33	56.67
14	60.00	69.63	60.00	63.33	60.00	53.33	70.00	85.00	80.00	76.00	66.67	60.00
15	58.52	57.04	73.33	80.00	73.33	63.33	55.00	65.00	60.00	72.00	60.00	56.67
16	71.85	69.63	73.33	80.00	60.00	63.33	90.00	85.00	48.00	52.00	56.67	56.67
17	66.67	63.70	63.33	73.33	86.67	76.67	100.00	85.00	72.00	68.00	66.67	63.33
18	78.52	74.81	70.00	70.00	53.33	60.00	95.00	95.00	64.00	60.00	70.00	63.33
19	68.89	71.11	73.33	76.67	73.33	76.67	80.00	65.00	80.00	80.00	66.67	63.33
20	77.04	72.59	80.00	73.33	66.67	70.00	95.00	85.00	68.00	76.00	56.67	63.33
21	74.07	71.11	66.67	73.33	63.33	66.67	80.00	60.00	76.00	76.00	70.00	70.00
22	66.67	67.41	80.00	86.67	70.00	83.33	75.00	70.00	56.00	64.00	63.33	73.33
23	71.85	79.26	80.00	83.33	66.67	66.67	85.00	80.00	72.00	80.00	73.33	66.67
24	75.56	74.07	70.00	66.67	50.00	53.33	80.00	80.00	76.00	76.00	60.00	70.00
25	62.96	65.93	63.33	76.67	53.33	73.33	85.00	85.00	60.00	64.00	50.00	70.00
26	59.26	72.59	66.67	76.67	70.00	63.33	80.00	100.00	52.00	60.00	63.33	70.00
27	68.15	68.89	80.00	76.67	73.33	66.67	85.00	100.00	68.00	64.00	66.67	66.67
28	74.07	73.33	76.67	66.67	70.00	60.00	60.00	60.00	76.00	72.00	83.33	76.67
29	62.96	65.93	70.00	66.67	50.00	53.33	80.00	80.00	60.00	64.00	60.00	70.00
30	65.19	65.19	76.67	80.00	50.00	56.67	60.00	40.00	72.00	76.00	66.67	66.67
31	72.59	74.81	73.33	73.33	60.00	60.00	100.00	100.00	60.00	64.00	76.67	83.33

Funding We gratefully acknowledge support from the Hibah Penelitian Unggulan Universitas – Universitas Negeri Jakarta under the contract number 25/KOMP-UNJ/LPPM/V/2020. Our simulations developed in the Digital Laboratory - Physics Education Department, Universitas Negeri Jakarta.

Data availability The authors confirm that the data supporting the findings of this study are available within the article. Raw data were generated at Learning Media Laboratory. Derived data supporting the findings of this study are available from the corresponding author Dewi Muliyati on request.

Code availability All code for data cleaning and analysis associated with the current submission is available at https://osf.io/5qwkb/. Any updates will also be published on Center of Open Science.

Declarations

Ethics approval

All participants in the research were purely voluntary and understood the process in which they were to be engaged. The participants' data were anonymized and kept confidential in the research.
All quantitative data sets of this research, which are anonymized, can be made available by individual application directly to the authors. The applicant should clearly describe where and how they will use the data sets in their contact letter. The applicant should also cite the source of the data sets in their ongoing papers. As an expert scientist and along with co-authors of the concerned field, the paper has been submitted with full responsibility, following the due ethical procedure, and there is no duplicate publication, fraud, plagiarism, or concerns about animal or human experimentation.

Consent to participate No clinical investigation is carried out on humans and animals.

Consent for publication Not applicable.

Conflicts of interest/competing interests The authors declare no conflict of interest, financial or otherwise.

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