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Investigation of science process skills and computational thinking dispositions during the implementation of collaborative modeling-based learning in high school physics class

Herwinarso[1]
Elisabeth Pratidhina[2]
Pramono Adam[3]
Heru Kuswanto[4]
Anggi Datiatur Rahmat[5]

(Corresponding Author)

[1,2]Department of Physics Education, Widya Mandala Surabaya Catholic University, Indonesia.
[1]Email: herwinarso@ukwms.ac.id
[2]Email: elisa.founda@ukwms.ac.id
[3]Anugrah Pekerti Junior High School, Surabaya, Indonesia.
[3]Email: Pramonoadam76@gmail.com
[4]Department of Physics Education, Universitas Negeri Yogyakarta, Indonesia.
[4]Email: Herukus61@uny.ac.id
[5]Department of Science Education, Universitas Negeri Yogyakarta, Indonesia.
[5]Email: anggidatiatur.2022@student.uny.ac.id

Abstract

Computational thinking (CT) skills are essential with the rapid advancement of technology. Developing CT attitudes in students is also required for improving CT skills. On the other hand, science process skills are also emphasized in high school physics classes. This study aims to design and implement collaborative modeling-based learning for high school physics classes that stimulates computational thinking (CT) and science process skills. The learning activities use a collaborative approach and adapt the modeling process that scientists usually use. A pilot study in a high school physics course was conducted to investigate the effectiveness of collaborative modeling-based learning. The research instruments used in this study include a test for assessing theoretical understanding, an observational rubric for assessing science process skills and a self-report checklist to assess CT dispositions. A pre-and post-test design is employed in the pilot study. Eighty-nine students participated in this study. Students who participated in collaborative modeling-based learning gained a theoretical understanding. Moreover, they have excellent science process skills. According to the self-report checklist, students also demonstrated positive CT attitudes and indicated that they planned to apply CT aspects to their learning. It indicates that the modeling process has engaged students to think computationally and develop their process skills.

Keywords: CT disposition, High school physics, Modeling-based learning, Science process skills.

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Contents

Contribution of this paper to the literature
This research contributes to the existing literature on modeling-based learning and the integration of computational thinking in physics education. This paper explains the adaptation of modeling activities in physics class. This study's new findings demonstrate that modelling activities may encourage students' CT dispositions.

1. Introduction

A significant technological development that has affected people's lifestyles in recent years encourages educational institutions to prepare students for a more dynamic life and demands job transformation. One of the crucial skills that students must possess is computational thinking (CT) (Esteve-Mon, Llopis, & Adell-Segura, 2020; Hsu, Chang, & Hung, 2018).

The CT concept emerged from the process carried out on computers that is adapted as an analytic approach to problem solving (Sengupta & Kinnebrew, 2013). CT is a fundamental skills just like writing, reading and arithmetic (Barr, Harrison, & Conery, 2011). CT comprises aspects of decomposition, abstraction, algorithmic thinking, generalization and evaluation (Voon, Wong, Wong, Khambari, & Syed-Abdullah, 2022; Yin, Hadad, Tang, & Lin, 2020). Problem-solving in science and engineering disciplines mainly requires thinking computationally (Li et al., 2020). Physics is closely related to CT. CT skills are used in most physics investigations. Hence, developing CT skills in high school physics has become necessary. Students may develop ideas relevant to CT by engaging in experiments, problem-solving and discussions during physics class.

Effective integration of CT with science has been the subject of several studies. For example, Yin et al. (2020) try to integrate CT with physics and engineering learning through activities they have designed. Sengupta and Kinnebrew (2013) have attempted to cultivate CT skills in elementary students using simulation and modeling to understand concepts in kinematics and ecology. Game-based learning has also enhanced CT (Yoon & Khambari, 2022). Students' tendency to apply CT is an important way to develop CT skills. The attitudinal tendency towards CT is called CT disposition. High school physics class has a crucial role in making CT disposition.

The high school physics curriculum also emphasizes scientific process skills (Susilawati, Doyan, Mulyadi, Abo, & Pineda, 2022). Scientific skills are behaviors that encourage skills to acquire knowledge (Gunawan, Hermansyah, & Herayanti, 2019). A specific approach to teaching high school physics classes is necessary to help students experience meaningful learning and help them acquire scientific process and CT abilities. Physicists usually use scientific methods and CT skills to understand physical phenomena. They always conduct modeling in their work. Modeling is a process of model construction to simplify a physical phenomenon. It helps physicists acquire new knowledge about natural phenomena. The modeling process may be incorporated into high school physics classes to train scientific skills and grow CT disposition.

In this research, we design and implement collaborative modeling-based learning which adapts modeling to the learning process. Collaborative modeling-based learning aims to cultivate students' science processes and CT skills. In modeling-based learning, students are encouraged to use the modeling process to develop their scientific knowledge (Campbell, Oh, Maughn, Kiriazis, & Zuwallack, 2015; Louca & Zacharia, 2012).

The following are the objectives of this research:

(1) Design collaborative modeling-based learning materials.
(2) Implement collaborative modeling-based learning in a high school physics class.
(3) Investigate the students' CT disposition and scientific process skills.

The present study is significant because it tries to find out alternative learning strategies that give students experiences to grow their CT dispositions and develop their skills. CT dispositions are fundamental for encouraging students to apply CT aspects in their life which is crucial in our current society.

2. Literature Review

2.1. Model and Modeling in Physics

Physics is a subject that aims to explore and understand how natural phenomena work. In physics, a model is used to simplify a part of the physical world so that the mechanism can be understood more easily. A model can be used to justify a physical phenomenon (Passmore, Gouvea, & Giere, 2013). The scientific model is an epistemological construction in natural science usually in interpretative representation (Nicolaou & Constantinou, 2014). As an epistemological entity, a model represents the characteristics of a natural phenomenon, explains the mechanism behind a phenomenon and can be used to predict a phenomenon. Some physicists also consider models as representations of a particular target that become a bridge between theory and experiment (Cascarosa, Sánchez-Azqueta, Gimeno, & Aldea, 2021). Modeling is a process of model construction from a physical phenomenon. Physicists always do modeling to understand, explain and predict a physical phenomenon. The modeling process involves various activities such as observation, experimentation, data analysis, data interpretation, etc.

2.2. Modeling-Based Learning

It is possible to modify the modelling method that physicists typically use for learning. During physics learning, students can be trained to construct a model, explain the consistency of the model based on evidence and explain the model's limitations (Krajcik & Merritt, 2012). There are some pedagogical purposes for engaging students in the modeling process. Students can develop their main conceptual view of science by involving them in modeling (Campbell et al., 2015; Dukerich, 2015). Students can also build their understanding of the nature of science.

The adaptation of modeling in the learning process creates the concept of modeling-based learning. There are some modeling-based learning processes proposed. Brewe (2008) proposed a learning syntax that consists of (1) introduction and representation, (2) coordination of representation, (3) application, (4) abstraction and generalization (5) and continued incremental development. Meanwhile, Halloun (2007) described a modeling-based learning processes that consists of (1) exploration, (2) model adduction, (4) model formulation, (5) model deployment and (6) paradigmatic synthesis. There is also modeling-based learning that is implemented in a flipped learning environment. The learning steps consist of (1) exploration, (2) model adduction, (3) model formulation, and (4) model deployment (Wang, Jou, Lv, & Huang, 2018). Implementation of modeling-based learning in school positively impacts reducing alternative conceptions, improving argumentation skills, helping students connect theory and experimental results, improving problem-solving skills and helping students understand the nature of science (Cascarosa et al., 2021).

Another framework that adapts the modeling process in science teaching is modeling instruction. Modeling instruction is based on conceptual model development and testing (Brewe & Sawtelle, 2018). There are two main steps of modeling instruction: model development and model deployment (Barlow, Frick, Barker, & Phelps, 2014). Model development consists of three activities, i.e., pre-laboratory, laboratory investigation and post-laboratory activity.

Demonstrations and discussions can be initiated in the pre-laboratory to stimulate students to question phenomena related to the learned topics. Subsequently, students can conduct laboratory investigations to clarify and answer the questions generated in the previous steps. Students are encouraged to formulate and evaluate the model based on the experimental results. In the post-laboratory activity, students communicate the new model they develop. Model deployment is a phase where students are asked to apply the model they build to another similar situation.

2.3. Computational Thinking Disposition

Recently, digital technology has developed tremendously. In the digital era, computational thinking (CT) must be acquired by students (Li et al., 2020). CT is a thinking skill in accordance with other important skills such as creativity, problem-solving and critical thinking (Yadav, Hong, & Stephenson, 2016). CT can be regarded as thinking skills that aim to solve the problem effectively by adapting the process that occurs in a computer (Selby & Woollard, 2013). CT consists of abstraction, decomposition, algorithmic thinking and pattern generalization (Psycharis & Kotzampasaki, 2019). CT development for students has been attracting attention from early childhood to university (Bilbao, Bravo, García, Rebollar, & Varela, 2021; Kafai & Proctor, 2022). Integration of CT in computer science, math, physics, chemistry, biology and art courses has been a particular strategy taken in the educational system to develop CT.

In addition to information and abilities, thinking requires certain attitudes. A person's attitudes, values, motivations and beliefs are components of their disposition (Sovey, Osman, & Matore, 2022). CT disposition can also be considered confident in dealing with complexity (Jong, Geng, Chai, & Lin, 2020). CT dispositions are the values, motivations, feelings and attitudes applicable to CT (Barr & Stephenson, 2011). It is a construct that describes an attitudinal tendency towards CT (Tsai, Liang, & Hsu, 2021). The CT dispositions category includes willingness to work cooperatively to accomplish a common goal, capacity to handle ambiguity, confidence in the face of complexity, determination in the face of hardship and recognition of one's own strengths and weaknesses when working cooperatively (Barr & Stephenson, 2011).

CT dispositions are essential since they are motivators for persistently distinguishing complex problems. It is also known that internal motivation positively correlates with thinking skills. Hence, measuring CT disposition is also necessary to design and evaluate a specific intervention in the learning process.

2.4. Science Process Skills

Scientists always use science process skills in order to construct new knowledge or solve a problem (Özgelen, 2012). It is necessary to discover and build scientific knowledge. Numerous studies divide scientific process skills into two categories: integrated scientific process skills and basic scientific process skills (Derilo, 2019). Basic scientific process skills include skills for observing, classifying, communicating, measuring, concluding and predicting (Darmaji, Kurniawan, & Irdianti, 2019; Mulyeni, Jamaris, & Suprjyati, 2019). Meanwhile, integrated scientific process skills comprise skills for controlling variables, constructing operational definitions, identifying and controlling variables, making hypotheses, experimenting and interpreting data (Elfeky, Masadeh, & Elbyaly, 2020).

2.5. Studies on Developing CT Disposition and Scientific Skills

Scientific skills can be cultivated by conducting active learning in the classroom. Students should be actively involved in investigating nature. Inquiry learning is one strategy to stimulate students in developing scientific skills (Baharom, Atan, Rosli, Yusof, & Hamid, 2020; Gunawan et al., 2019; Limatahu, Sutoyo, & Prahani, 2018).The discovery learning model and problem -based learning model are also effective in improving scientific skills along with the inquiry learning model (Suryanti, Widodo, & Budijastuti, 2020). Media used in learning activities can boost scientific skill acquisition (Osman & Vebrianto, 2013). For instance, using multimedia practicum has been shown to enhance scientific process skills (Kurniawan et al., 2019).

There is still a limited study on the improvement of CT disposition in science class. However, active learning in science class may also grow CT disposition. A study conducted by Yin et al. (2020) indicates that integrating maker activities and physics classes can enhance the CT disposition of students.

3. Method

3.1. Research Design

The effectiveness of collaborative modeling-based learning in high school physics courses is investigated through a pilot study. Developing scientific skills is one of the primary purposes of physics courses. Students' scientific skills are also assessed based on the students' work on the modeling module. The pilot study has two learning cycles with sub-topics of Hooke's law and spring arrangement respectively. The CT disposition is investigated by asking students to complete a self-report checklist. The impact of the intervention on the students' theoretical understanding is also investigated. A pre-and post-tests design was implemented in the study. Pre- and post-tests were given before and after students participated in the collaborative modeling-based learning in the physics classroom.

3.2. Research Participants

The pilot study was done in a private school in Surabaya, Indonesia. Students in grade 11th participated in the pilot study. In total, there are 89 participants which consist of 27 male and 62 female students.

3.3. Instruments

The research instruments employed in the study are pre- and post-tests, CT dispositions checklists and scientific skills rubrics. The pre-and post-tests consist of five essay problems about elasticity. Students are asked to fill out a self-report checklist to assess their CT disposition. The checklist consists of several statements about CT disposition on a scale of 1-4. Students' work at each learning cycle was assessed using a rubric to measure students' science process skills.

3.4. Data Analysis

The scores of the pre- and post-tests are compared and the normalized gain score is calculated. The formula to calculate the normalized gain score $\langle g \rangle$, is given as:

$$\langle g \rangle = \frac{\%post - \%pre}{100 - \%pre} \quad (1)$$

Where $\%pre$ is the percentage of the pre-test score and $\%post$ is the percentage of the post-test score. The $\langle g \rangle$ score is then classified using criteria given in Hake (1998).

Students' CT dispositions are measured by using a checklist. The students' answers on each item on the checklist are converted into score such as "strongly disagree" = 1, "disagree" = 2, "agree" = 3 and "strongly agree" = 4. The mean CT disposition score is interpreted using criteria as shown in Table 1.

Table 1. Criteria for the average score of students' CT dispositions checklist.

No.	Score interval	Criteria
1	$\bar{X} > 3.4$	Very good
2	$2.8 < \bar{X} \leq 3.4$	Good
3	$2.2 < \bar{X} \leq 2.8$	Acceptable
4	$1.6 < \bar{X} \leq 2.2$	Poor
5	$\bar{X} \leq 1.6$	Very poor

4. Results and Discussions

4.1. Learning Process

The learning syntax is constructed by adapting the modeling process. It consists of model development and model deployment. Model development is divided into pre-and post-experiment and investigation. Meanwhile, model deployment comprises model application and reflection. Each stage is explained in Table 2.

Table 2. The stages of collaborative-modeling-based learning.

Stages	Activity explanation
Pre-experiment	Students are asked to observe a film that depicts real-world occurrences related to the subjects discussed in the pre-experiment activity. This activity aims to engage students at the beginning of the class. Students are also stimulated to ask questions and construct hypotheses.
Investigation	Students have to explore the elasticity phenomenon through collaborative experiments. They plan experiments, arrange the apparatus, observe the phenomena, collect the data and make documentation. During group investigations, the teacher has a role in monitoring how the investigation goes. An experiment guide is provided along with the worksheet.
Post-experiment discussion	Students discuss the results of the investigation in the group. They are stimulated to analyze the data and interpret it. Students are asked to develop a model based on the data. A whiteboard is provided for each group to facilitate model construction. After each group, builds the model, they are asked to communicate it in the class forum. During the class discussion, other groups can ask questions or suggest an idea to improve the constructed model.
Model application	Students discuss how to solve some related problems by applying the model that has been developed within the group.
Reflection	Students are asked to make a reflection on the learning activity.

4.2. Scientific Process Skills

Some aspects of scientific process skills are observed in this study, i.e., observing, formulating hypotheses, experimenting, classifying, visualizing, interpreting, concluding and communicating. Figure 1 shows the average score of each scientific process skill aspect in percentage during the first and second learning processes. All of the aspects improve from learning cycle 1 to learning cycle 2. In learning cycle 1, the hypothesis that was observed and formulated can be classified as acceptable. Meanwhile, the aspects of experimenting, classifying, visualizing, interpreting, concluding and communicating can be classified as good. In learning cycle 2, students seem to be getting familiar with the modeling process; hence, their scientific process skills improve. The score for formulating a hypothesis in the learning cycle improves and can be categorized as good. Meanwhile, the others change significantly to be excellent.

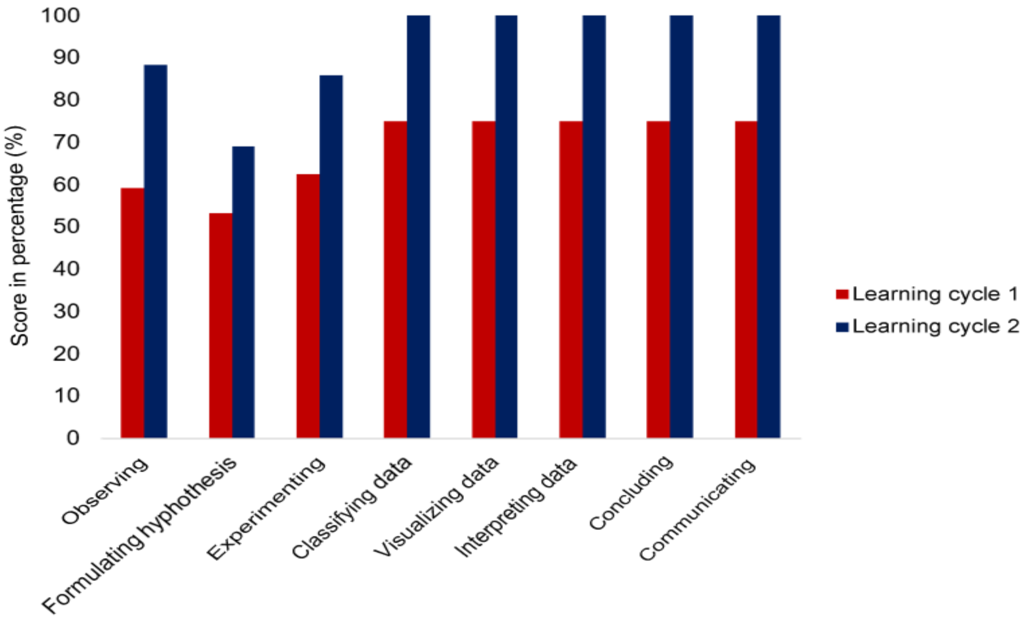

Figure 1. The score of observed science process skills during learning cycle 1 and learning cycle 2.

Table 3. Pre-test and post-test results.

Number of participants	Average pre-test score	Average post-test score	Average $\langle g \rangle$	Classification
89	21.3	81.7	0.77	High

The modeling process supports students in acquiring cognitive domains since during the modeling process, students use analyzing, relational reasoning, synthesizing, testing and debugging (Louca & Zacharia, 2012). Previous studies also showed a positive impact of the modeling process on conceptual understanding and other cognitive domains (Campbell et al., 2015; Dukerich, 2015; Taqwa & Taurusi, 2021; Xue, Sun, Zhu, Huang, & Topping, 2022). Collaborative modeling-based learning is a form of constructivist learner-centered instructional method. Students construct their own understanding of physical phenomena according to the interaction between the existing information in their minds and information deduced from observation and social contact. Supena, Darmuki, and Hariyadi (2021) revealed that constructivist and collaborative approach positively influence students learning outcomes.

4.3. Computational Thinking Disposition

Collaborative modeling-based learning examines many CT dispositions such as resilience in the face of adversity, ambiguity handling skills, confidence in the face of complexity and teamwork in pursuing a common goal. Each CT disposition is described in some statements in the questionnaires (see Table 4). Students have good confidence when facing complexity, good persistence when working with difficulty and good collaboration ability. The score on those aspects is above 2.80 (out of 4.00) based on the self-report checklist. However, students seem to be confident in handling ambiguity. The average score for that aspect is 2.54 (out of 4.00) which is only categorized as acceptable.

Table 4. Score of CT dispositions.

No	CT dispositions aspects	Statements	Average score	Average score of each aspect	Criteria
1	Confidence when facing complexity	I feel confident when facing complex problems.	2.63	3.00	Good
		I am able to solve complex problems if I continuously try.	3.23		
		I am able to solve complex problems at an appropriate time.	3.14		
2	Persistence when working with difficulty	I tried my best to work on difficult questions.	3.13	2.89	Good
		I am very persistent when working to solve problems.	2.78		
		I want to have extra time and put more effort into dealing with complex problems.	2.77		
3	Ability to handle ambiguity	I can solve open-ended questions (Problems that do not have only one solution).	2.44	2.54	Acceptable
		I can solve questions that have more than one answer.	2.63		
		I am not easily ambiguous (Confused) in working on questions.	2.55		
4	Skills to work collaboratively to achieve a common goal	I can communicate and work well with the team when I have to accomplish a common goal.	3.16	3.08	Good
		I was a reliable team member when working on a team.	2.92		
		I can work in groups productively.	3.15		

Table 5. Frequency of using CT.

No	Statements	Average score	Criteria
1	I attempt to deconstruct complicated issues into simpler components to make them easier to comprehend and resolve.	3.06	Good
2	When addressing complicated issues, I collect broad characteristics and filter out specific details that are unnecessary for the problem's solution.	3.06	Good
3	I'm looking for similarities or patterns between questions to find a solution.	3.08	Good
4	I reduce complexity and look for main ideas through modes.	2.83	Good
5	I have developed a step-by-step solution that can be followed to solve many problems.	3.16	Good
6	I assess how it might be improved after resolving an issue.	3.05	Good
7	I determine whether the solution is truly correct and efficient after finding a solution to a problem.	3.11	Good
8	I considered several different approaches to the problem and evaluated their benefits and drawbacks before selecting the best one.	3.11	Good
Average		3.06	Good

The self-report checklist indicates that students used CT elements while engaging in collaborative modeling-based learning (see Table 5). The preliminary result indicates that CT skills may be developed through collaborative modeling-based learning, despite the fact that our study did not thoroughly examine the CT skills outcomes. Students can practice CT aspects through modeling-based learning while constructing, evaluating, revising and applying the model. Previous studies also support the finding (Hutchins et al., 2020; Liu, Perera, & Klein, 2017). Hutchins et al. (2020) showed that incorporating a learning-by-modeling approach using computer simulation improves CT skills. Shin, Bowers, Krajcik, and Damelin (2021) also explain that modeling process features in project-based learning that they have implemented can support CT development.

Students can practice CT skills when they are actively engaged in the modeling process. The initial finding of this study is in alignment with studies showing that active learning stimulates students to practice CT (Jun, Han, & Kim, 2017; Romero, Lepage, & Lille, 2017). Gao and Hew's (2022) study provides evidence that integrating active learning into the 5E framework (engagement, exploration, explanation, elaboration and evaluation) improves students' comprehension of CT ideas and their ability to solve problems.

5. Conclusion

In this study, we designed collaborative modeling-based learning to foster theoretical understanding, science process skills and CT dispositions in high school physics classes. Collaborative modeling-based learning engages students in a modeling process that is usually done by a physicist. Collaborative modeling-based learning comprises some stages, i.e., pre-experiment, investigation, post-experiment discussion, model application and reflection.

After students participated in collaborative modeling-based learning, they had excellent theoretical knowledge. Direct experiences to observe physical phenomena and social interaction during the collaboration with the peer support students to build their own knowledge. Moreover, students' scientific process skills improve during the learning cycle. In the last cycle, students had excellent scientific skills. By being involved in the modeling process, students have direct experiences with practicing science; hence, it can foster the students' scientific skills.

It has also been found that collaborative modeling-based learning can contribute to developing computational thinking. Activities in the modeling stimulate CT competence. We conducted an initial investigation by using a self-report checklist to evaluate CT disposition and frequency of using CT aspects. We found that students have good CT dispositions and use CT aspects.

5.1. Limitation and Prospective Recommendation

This study has some limitations. CT disposition is only investigated through a self-report checklist which is less comprehended. Observation should be carefully performed to explore more about the impact on CT disposition and CT skills. Collaborative modeling-based learning involves laboratory work in which experimentation apparatus is necessary. In some schools, experimentation apparatus is still limited. Hence, an innovation to provide alternative options should be created. One of them is providing mobile laboratories for schools in distant areas. The development of such media will be our next project to widen the impact of collaborative modeling-based learning.

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