JPPIPA 12(3) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Promoting Quality Education through Physics Simulations and Collaborative Modeling-Based Learning: Students' Computational Thinking Dispositions in High School Physics

Elisabeth Pratidhina Founda Noviani[1*], Firza Farahdiba Daeng[1], Anthony Wijaya[1], Herwinarso[1]

[1] Physics Education Study Program, Universitas Katolik Widya Mandala Surabaya, Surabaya, Indonesia.

Received: December 04, 2025
Revised: February 27, 2026
Accepted: March 25, 2026
Published: March 31, 2026

Corresponding Author:
Elisabeth Pratidhina Founda Noviani
elisa.founda@ukwms.ac.id

DOI: 10.29303/jppipa.v12i3.13724

Abstract: Computational thinking skills are essential in the 21st century; therefore, educational institutions must facilitate students in cultivating computational thinking skills. In addition, computational thinking dispositions are also important for students, as a positive attitude toward computational thinking will help them acquire the skills. This study aims to design and implement a collaborative modeling-based physics learning model supported by simulations to cultivate students' computational thinking dispositions. The learning model was implemented in a senior high school physics classroom during instruction on the work and energy topic. Thirty-four students participated in the study. At the end of the learning process, students' computational thinking dispositions were assessed using a questionnaire. The results showed that students have overall computational thinking dispositions that are at a good level, particularly in confidence, persistence, and collaboration, while their ability to handle ambiguity reached an acceptable level. Moreover, according to the self-assessment, students had frequently engaged in computational thinking practices during the learning activities. These findings suggest that collaborative modeling-based learning supported by physics simulations has strong potential to promote computational thinking dispositions.

Keywords: Computational thinking dispositions; Modeling-based learning; Physics; Simulation

Introduction

In recent decades, technology has developed tremendously, giving rise to Industrial Revolution 4.0, which stimulated job transformation. This fact encourages educational institutions to prepare students to face the job transformation (Azmi & Ummah, 2021). One of the critical skills that students must possess is computational thinking skills (Esteve-Mon et al., 2020; Hsu et al., 2018). Computational thinking has been described as an analytic approach to problem-solving that adapts the process on the computer (Sengupta & Kinnebrew, 2013). Furthermore, it becomes one of the fundamental skills, along with writing, reading, and arithmetic (Barr et al., 2011). Computational thinking is a problem-solving process that consists of decomposition, abstraction, algorithmic thinking, generalization, and evaluation (Voon et al., 2022; Yin et al., 2020). Decomposition can be defined as a method to break down larger tasks into smaller and simpler ones so that the task can be solved more easily (Kwon & Cheon, 2019; Rijke et al., 2018). Pattern recognition or generalization is recognizing the similarities, patterns, trends, and regularities of data or objects (Saxena et al., 2020). Abstraction is a process of omitting unnecessary information in a system so it becomes easier to focus on the relevant information (Fagerlund et al., 2021). Algorithmic thinking is an ability related to creating and processing a sequence of logical steps to perform a well-defined task (Katai, 2015).

How to Cite:
Noviani, E. P. F., Daeng, F. F., Wijaya, A., & Herwinarso. Promoting Quality Education through Physics Simulations and Collaborative Modeling-Based Learning: Students' Computational Thinking Dispositions in High School Physics. *Jurnal Penelitian Pendidikan IPA*, *12*(3), 67-73. https://doi.org/10.29303/jppipa.v12i3.13724

Computational thinking has become essential to science, technology, engineering, and mathematics (STEM). Problem-solving in science and engineering disciplines mainly requires thinking computationally (Li et al., 2020). The Next Generation Science Standards (NGSS) include computational thinking as part of the core scientific practices (NGSS, 2013).

Several studies have examined how to effectively integrate computational thinking into STEM. For example, Yin et al. (2020) try to integrate computational thinking with physics and engineering learning through maker activities they have designed. Sengupta et al. (2013) have attempted to cultivate computational thinking skills in elementary students using simulation and modeling to understand concepts in kinematics and ecology. Peel et al. (2021) incorporate the computational thinking in 10th grade biology class, the learning process using unplugged or without computer-based activity. During the learning process, students use computational thinking practices to explain the natural selection algorithmically. The combination of computational thinking and science content can help students learn natural selection and develop computational thinking skills (Peel et al., 2021). Hutchins et al. (2019) designed a collaborative computational STEM (C2STEM) program to scaffold learning in high school physics using a computational modeling approach. According to the study, students who learn kinematics through C2STEM significantly improve their computational thinking test scores. In a study conducted by Hanid et al. (2022); they use a computational thinking approach with the assistance of augmented reality in the math subject. During the learning process with augmented reality assistance, components of computational thinking, such as abstraction, generalization, decomposition, and algorithms, can be identified. Game-based learning has also been employed to enhance computational thinking (Yoon & Khambari, 2022). In addition, computational thinking skills are also cultivated through project-based learning (Ridlo et al., 2022) and problem-based learning (Pangsuma et al., 2025).

Theoretically, to develop computational thinking skills optimally, students must have a positive attitude towards computational thinking. The attitudinal tendency towards computational thinking is called computational thinking disposition. Developing computational thinking dispositions in the science classroom has become necessary. Hence, research on computational thinking dispositions is also important. One framework with potential is modeling-based learning. Modeling is a process scientists use to construct a scientific model. In modeling-based learning, students are encouraged to use the modeling process to develop their scientific knowledge (Campbell et al., 2015; Louca & Zacharia, 2012). Physics simulation on a smartphone can be used as a learning medium to help students explore physics phenomena, especially related to the energy concept (Yusuf et al., 2024). Hence, simulation can support the modeling process.

Although previous studies have integrated computational thinking into science learning through various scenarios, such as maker activities and game-based learning, limited studies have specifically examined how collaborative modeling-based learning supported by simulations affects students' computational thinking dispositions. Many existing studies focus on skill development rather than attitudinal readiness to engage in computational thinking practice within a physics learning context. By combining a collaborative approach, modelling-based instruction, and physics simulations, this study offers a novel instructional approach that meets current demands for quality physics education and supports the development of computational thinking dispositions.

Literature Review

Modeling-based learning

A model in science represents the characteristics of a natural phenomenon, explains the mechanism behind it, and can be used to predict it. Teaching and learning in science adopt the construction of a scientific model as a learning approach. The approach is called modeling-based learning. In modeling-based learning, students are stimulated to construct models as representations of physical phenomena. They can represent physical objects and their characteristics, physical entities, or physical processes (Louca & Zacharia, 2011). According to some studies, modeling-based learning has the potential for enhancing science teaching and learning. Involving students in model construction helps them develop a conceptual view of science. It also helps students to understand the nature of science (Campbell et al., 2015; Dukerich, 2015).

Collaborative learning

In the 21st century, collaboration has become a trend in many fields. It is due to increased societal awareness of the importance of working together to solve a problem. Collaborative learning is an approach in education that stimulates learners to work together in groups to find a problem solution, complete a project, or make a certain product (Laal & Laal, 2012). During collaborative learning, students are motivated to ask questions, give explanations, share arguments, create new ideas, and find solutions (van Leeuwen & Janssen, 2019).

Some studies indicate that students who engage in collaborative learning achieve higher levels of thought and retain information longer than those who study individually (Laal & Laal, 2012). The cooperation gives students a chance to engage in discussion, but they must still take responsibility for their own learning. It encourages students to become critical thinkers (Wulandari & Rohaeti, 2024). Collaborative learning also stimulates students to develop their science process skills (Nuha et al., 2023).

Collaborative learning is a form of student-centered learning in which students are required to be active, with the teacher serving as a facilitator. As a facilitator in collaborative learning, the teacher plays a crucial role in fostering good student interactions (Kaendler et al., 2015). Guidance from a teacher is needed to create positive interactions during the learning process.

Simulations

As computer technology has developed tremendously, the use of computers in the learning process has improved significantly (De Witte et al., 2015; Kleij et al., 2015). Various technologies are available to stimulate students' engagement in physics learning. One of them is computer simulation. Computer simulations are dynamic models on a computer that present theoretical or simplified models of real phenomena (Kabigting, 2021). Simulations can serve as a bridge between students' prior knowledge and new physical concepts. In a previous study, simulations were used to encourage students to be active in the learning process and engage in higher-order thinking (Darwis & Hardiansyah, 2023; Rukmi et al., 2025). Simulations also allow students to manipulate parameters and investigate phenomena that would not be possible to experience in a classroom or even in a laboratory (Rutten et al., 2012). In modeling-based learning, computer simulations can support exploration. The use of computer simulations has been shown to enhance students' learning motivation, problem solving, and science learning outcomes (Hidayati et al., 2025; Pratiwi et al., 2025).

Computational Thinking Disposition

In this era, students must acquire computational thinking. Computational thinking can be regarded as a set of thinking skills aimed at solving problems effectively by adapting the processes used by a computer. In addition, thinking requires certain attitudes. A person's attitudes, values, motivations, and beliefs are components of their disposition (Sovey et al., 2022). A computational thinking disposition is confident in dealing with complexity (Jong et al., 2020). Computational thinking dispositions are the values, motivations, feelings, and attitudes applicable to computational thinking (Barr & Stephenson, 2011). To develop computational thinking skills, disposition should be considered an important factor.

Method

In this study, collaborative modeling-based learning was implemented in one physics classroom at a senior high school, focusing on work and energy topics. Thirty-four students participated in this study. At the end of the learning process, students were directed to complete a questionnaire to assess their computational thinking disposition. There were 4 aspects of computational thinking dispositions being assessed, i.e., (1) confidence when facing complexity, (2) persistence when working with difficulty, (3) ability to handle ambiguity, and (4) ability to work collaboratively to achieve a common goal. The checklist used 1-4 Likert scale to assess four computational thinking disposition aspects. To analyze the computational thinking disposition, the scores were averaged and converted into qualitative criteria as given in Table 1.

Table 1. Conversion of Scale to Qualitative Criteria

Score interval	Criteria
$\overline{X} > 3.4$	Very good
$2.8 < \overline{X} \leq 3.4$	Good
$2.2 < \overline{X} \leq 2.8$	Acceptable
$1.6 < \overline{X} \leq 2.2$	Poor
$\overline{X} \leq 1.6$	Very poor

Result and Discussion

The learning scenario of collaborative modeling-based learning is given in Table 2. After students actively participated in collaborative physics modeling, their computational thinking dispositions were assessed by asking them to complete a questionnaire.

Table 2. Learning Scenario

Stages	Activity
Meeting 1: Work, Force, and Displacement	
Pre-experiment	Students observed a video and teacher's demonstration related to the concept of work in physics. The teacher asked students several engagement questions. Students were also encouraged to question and construct hypotheses.
Investigation	Students explored the relations among work, force, and displacement through simulations. Students observed the phenomena and collected the data. Previously, the teacher prepared a worksheet to guide students to do investigations.

Stages	Activity
Post-experiment Discussion	Using the collected data, students were asked to model the relationships among work, force, and displacement. Then, each group was asked to share their results in the class forum. Other groups were invited to ask questions or share ideas to improve the model.
Model application	Students worked in groups to find solutions to several problems by applying the model that had been developed.
Reflection	The teacher guided the students to reflect on the learning process.
Meeting 2: Conservations of Mechanical Energy	
Pre-experiment	Students observed a video related to mechanical energy conservation
Investigation	Students explored PhET simulations related to the conservation of mechanical energy. Students observed the phenomena and collected the data on potential and kinetic energy.
Post-experiment Discussion	Within the group, students discussed how to model the change of mechanical energy, kinetic energy, and potential energy each time. After discussions, students shared the results in the class forum.
Model application	The teacher presented a problem related to mechanical energy conservation. Then, students discussed how to solve the problem with the model that has been constructed.
Reflection	The teacher and the students conducted reflection on the learning process.

Table 3 presents the checklist statements along with the average score for each aspect. As shown, at the end of the learning process, students have high confidence in their ability to handle complexity (mean = 3.04). They also have good persistence when working with difficulty (mean = 2.92). Students are also good at working collaboratively to achieve a common goal (mean = 2.88). Meanwhile, students' ability to handle ambiguity is acceptable (mean = 2.50). According to the data, the learning process through modeling-based learning supported by simulations can stimulate students' disposition in computational thinking.

Table 3. Students' Computational Thinking Dispositions after Participating in Collaborative Modeling-Based Learning for Work and Energy Topics

CT dispositions aspects	Average score of each aspect	Criteria
Confidence when facing complexity	3.04	Good
Persistence when working with difficulty	2.92	Good
Ability to handle ambiguity	2.5	Acceptable
Ability to work collaboratively to achieve a common goal	2.88	Good

Table 4. Frequency of Using Computational Thinking

Statements	Average score	Criteria
I try to break down complex problems into simpler parts to make them easy to understand and solve.	3.03	Good
When facing complex problems, I gather general characteristics and filter out specific information that is unnecessary to solve the problem.	2.82	Good
I'm looking for similarities or patterns between questions to find a solution.	3.06	Good
I reduce complexity and look for main ideas through modes.	2.88	Good
To solve many problems, I have developed a step-by-step solution that can be followed.	3.12	Good
After solving a problem, I evaluate how the solution can be improved.	3.12	Good
After finding a solution to a problem, I determine whether the answer is truly correct and efficient.	3.15	Good
I compared the advantages and disadvantages of various alternative solutions to the problem and took the best one.	3.18	Good
Average	3.04	Good

The results of the self-assessment regarding the frequency of computational thinking practice aspects show that computational thinking application during learning is categorized as good (see Table 4). Although our research has not explored in depth the outcomes of computational thinking skills, preliminary findings suggest that these skills can be developed through collaborative physics modeling learning. Students were able to internalize key aspects of computational thinking through model construction, revision, and application activities. Previous research also supports these findings (Hutchins et al., 2020; Liu et al., 2017). Hutchins et al. (2020) shows that a modeling learning approach using computer simulation improves computational thinking skills. In addition, using PhET has been shown to be effective in improving problem-solving skills (Mashami et al., 2023) which is in line with the computational thinking practice.

Conclusion

This research shows that collaborative modeling-based physics learning supported by simulations can foster positive computational thinking dispositions among high school students. The findings indicate improvement in students' confidence, persistence, and collaborative tendencies while engaging with computational problem-solving tasks in the physics context. However, the findings reflect students' attitudinal readiness rather than direct mastery of computational thinking skills. Thus, while the implementation of the learning model demonstrates strong potential to support the development of computational thinking, further study using performance-based assessment is required to comprehensively investigate its impact on students' computational thinking skills.

Acknowledgments
The authors would like to express our gratitude to Widya Mandala Surabaya Catholic University for supporting this study.

Author Contributions
Conceptualization E.P.F.N and H; Methodology and Instrument Preparation A.W.; Data Collection F.F.D; Data Analysis E. P. F. N; All authors contributed to the paper writing.

Funding
This research is funded by Widya Mandala Surabaya Catholic University.

Conflicts of Interest
The authors declare no conflict of interest.

References

Azmi, R. D., & Ummah, S. K. (2021). Implementasi Project Based Learning Untuk Mengeksplorasi Kemampuan Computational Thinking Mahasiswa. *Jurnal Ilmiah Pendidikan Matematika AL-QALASADI*, *5*(1), 52–61. https://doi.org/10.32505/qalasadi.v5i1.2761

Barr, D., Harrison, J., & Conery, L. (2011). Computational Thinking: A Digital Age Skill for Everyone. *Learning and Leading with Technology*, *38*(6), 20–23. Retrieved from https://files.eric.ed.gov/fulltext/EJ918910.pdf

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads*, *2*(1), 48–54. https://doi.org/10.1145/1929887.1929905

Campbell, T., Oh, P. S., Maughn, M., Kiriazis, N., & Zuwallack, R. (2015). A Review of Modeling Pedagogies : Pedagogical Functions, Discursive Acts , and Technology in Modeling Instruction. *Eurasia Journal of Mathematics, Science & Technology Education*, *11*(1), 159–176. https://doi.org/10.12973/eurasia.2015.1314a

Darwis, R., & Hardiansyah, M. R. (2023). Effect of PhET virtual laboratory implementation on students' higher order thinking skills. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1922–1928. https://doi.org/10.29303/jppipa.v9i4.1979

De Witte, K., Haelermans, C., & Rogge, N. (2015). The effectiveness of a computer-assisted math learning program. *Journal of Computer Assisted Learning*, *31*(4), 314–329. https://doi.org/10.1111/jcal.12090

Dukerich, L. (2015). Applying Modeling Instruction to High School Chemistry To Improve Students' Conceptual Understanding. *Journal of Chemical Education*, *92*, 1315–1319. https://doi.org/10.1021/ed500909w

Esteve-Mon, F. M., Llopis, M. A., & Adell-Segura, J. (2020). Digital competence and computational thinking of student teachers. *International Journal of Emerging Technologies in Learning*, *15*(2), 29–41. https://doi.org/10.3991/ijet.v15i02.11588

Fagerlund, J., Häkkinen, P., Vesisenaho, M., & Viiri, J. (2021). Computational thinking in programming with Scratch in primary schools: A systematic review. *Computer Applications in Engineering Education*, *29*(1), 12–28. https://doi.org/10.1002/cae.22255

Hanid, M. F. A., Said, M. N. H. M., Noraffandy Yahaya, & Abdullah, Z. (2022). The Elements of Computational Thinking in Learning Geometry by Using Augmented Reality Application. *International Journal of Interactive Mobile Technologies*, *16*(2), 28–41. https://doi.org/10.3991/ijim.v16i02.27295 Mohd

Hidayati, N., Munasir, M., Anggaryani, M., & Satriawan, M. (2025). Implementation of PhET simulation on motion material to improve problem solving skills of middle school students. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 919–927. https://doi.org/10.29303/jppipa.v11i8.11592

Hsu, T. C., Chang, S. C., & Hung, Y. T. (2018). How to learn and how to teach computational thinking: Suggestions based on a review of the literature. *Computers and Education*, *126*(July), 296–310. https://doi.org/10.1016/j.compedu.2018.07.004

Hutchins, N. M., Biswas, G., Maróti, M., Lédeczi, Á., Grover, S., Wolf, R., Blair, K. P., Chin, D., Conlin, L., Basu, S., & Mcelhaney, K. (2020). C2STEM : a System for Synergistic Learning of Physics and Computational Thinking. *Journal of Science Education and Technology*, *29*, 83–100. https://doi.org/10.1007/s10956-019-09804-9

Jong, M. S. Y., Geng, J., Chai, C. S., & Lin, P. Y. (2020). Development and predictive validity of the computational thinking disposition questionnaire. *Sustainability (Switzerland)*, *12*(11). https://doi.org/10.3390/su12114459

Kabigting, L. D. C. (2021). Computer Simulation on Teaching and Learning of Selected Topics in Physics. *European Journal of Interactive Multimedia and Education*, *2*(2), e02108. https://doi.org/10.30935/ejimed/10909

Kaendler, C., Wiedmann, M., Rummel, N., & Spada, H. (2015). Teacher competencies for the implementation of collaborative learning in the classroom: A framework and research review. *Educational Psychology Review*, *27*(3), 505–536. https://doi.org/10.1007/s10648-014-9288-9

Katai, Z. (2015). The challenge of promoting algorithmic thinking of both sciences- and humanities-oriented learners. *Journal of Computer Assisted Learning*, *31*, 287–299. https://doi.org/10.1111/jcal.12070

Kleij, F. M. Van Der, Feskens, R. C. W., & Eggen, T. J. H. M. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes : A meta-analysis. *Review of Educational Research*, *85*(4), 1–37. https://doi.org/10.3102/0034654314564881

Kwon, K., & Cheon, J. (2019). Exploring problem decomposition and program development through block-based programs. *International Journal of Computer Science Education in Schools*, *3*(1), 3–16. https://doi.org/10.21585/ijcses.v3i1.54

Laal, M., & Laal, M. (2012). Collaborative learning: What is it? *Procedia - Social and Behavioral Sciences*, *31*(2011), 491–495. https://doi.org/10.1016/j.sbspro.2011.12.092

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2020). On Computational Thinking and STEM Education. *Journal for STEM Education Research*, *3*(2), 147–166. https://doi.org/10.1007/s41979-020-00044-w

Liu, H. P., Perera, S. M., & Klein, J. W. (2017). Using Model-Based Learning to Promote Computational Thinking Education. In *Emerging Research, Practice, and Policy on Computational Thinking* (pp. 153–172). https://doi.org/10.1007/978-3-319-52691-1

Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education : cognitive, metacognitive, social, material and epistemological contributions. *Educational Review*, *64*(4), 471–492. https://doi.org/10.1080/00131911.2011.628748

Mashami, R. A., Ahmadi, Kurniasih, Y., & Khery, Y. (2023). Use of PhET simulations as a virtual laboratory to improve students' problem solving skills. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11455–11465. https://doi.org/10.29303/jppipa.v9i12.6549

Nuha, U., Scisnayani, Y., Supeno, Wahyuni, D., & Rusdianto. (2023). Development of collaborative-based worksheets to improve science process skills in science learning. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5390–5397. https://doi.org/10.29303/jppipa.v9i7.2927

Pangsuma, N. S., Purwianingsih, W., & Kusumastuti, M. N. (2025). Empowering computational thinking through PBL-SSI: Tackling conservation threats effectively. *Jurnal Penelitian Pendidikan IPA*, *11*(5), 725–732. https://doi.org/10.29303/jppipa.v11i5.10359

Peel, A., Sadler, T. D., & Friedrichsen, P. (2021). Using Unplugged Computational Thinking to Scaffold Natural Selection Learning. *American Biology Teacher*, *83*(2), 112–117. https://doi.org/10.1525/abt.2021.83.2.112

Pratiwi, N. K. R., Sudiatmika, A. A. I. A. R., & Pujani, N. M. (2025). Utilizing PhET simulator in guided inquiry learning to enhance students motivation and science learning outcomes. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 479–485. https://doi.org/10.29303/jppipa.v11i10.11368

Ridlo, Z. R., Supeno, S., Wahyuni, S., Wicaksono, I., & Ulfa, E. M. (2022). Analysis of implementation project-based learning model of teaching integrated with computer programming in improving computational thinking skills in a classical mechanics course. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2029–2035. https://doi.org/10.29303/jppipa.v8i4.1789

Rijke, W. J., Bollen, L., Eysink, T. H. S., & Tolboom, J. L. J. (2018). Computational thinking in primary school: An examination of abstraction and decomposition in different age groups. *Informatics in Education*, *17*(1), 77–92. https://doi.org/10.15388/infedu.2018.05

Rukmi, J. N. P., Fadhli, M., Kurniawan, C., & Degeng, M. D. K. (2025). Integration of problem-based learning model assisted by digital simulation to improve students analytical skills: Literature review. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 33–42. https://doi.org/10.29303/jppipa.v11i12.13327

Rutten, N., Van Joolingen, W. R., & Van Der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers and Education*, *58*(1), 136–153. https://doi.org/10.1016/j.compedu.2011.07.017

Saxena, A., Lo, C. K., Hew, K. F., & Wong, G. K. W. (2020). Designing Unplugged and Plugged Activities to Cultivate Computational Thinking: An Exploratory Study in Early Childhood Education. *Asia-Pacific Education Researcher*, *29*(1), 55–66. https://doi.org/10.1007/s40299-019-00478-w

Sengupta, P., & Kinnebrew, J. S. (2013). Integrating computational thinking with K-12 science education using agent-based computation : A theoretical framework. *Education and Information Technologies*, *18*, 351–380. https://doi.org/10.1007/s10639-012-9240-x

Sovey, S., Osman, K., & Matore, M. E. E. M. (2022). Rasch Analysis for Disposition Levels of Computational Thinking Instrument Among Secondary School Students. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(3), 2–15. https://doi.org/10.29333/ejmste/11794

van Leeuwen, A., & Janssen, J. (2019). A systematic review of teacher guidance during collaborative learning in primary and secondary education. *Educational Research Review*, *27*, 71–89. https://doi.org/10.1016/j.edurev.2019.02.001

Voon, X. P., Wong, S. L., Wong, L. H., Khambari, M. N. M., & Syed-Abdullah, S. I. S. (2022). Developing Computational Thinking Competencies through Constructivist Argumentation Learning: A Problem-Solving Perspective. *International Journal of Information and Education Technology*, *12*(6), 529–539. https://doi.org/10.18178/ijiet.2022.12.6.1650

Wulandari, T., & Rohaeti, E. (2024). Research-oriented collaborative inquiry learning (REORCILEA) model: Improvement of students' critical thinking ability and collaborative skills in thermochemistry of materials. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6809–6814. https://doi.org/10.29303/jppipa.v10i9.8355

Yin, Y., Hadad, R., Tang, X., & Lin, Q. (2020). Improving and Assessing Computational Thinking in Maker Activities : the Integration with Physics and Engineering Learning. *Journal of Science Education and Technology*, *29*, 189–214. https://doi.org/10.1007/s10956-019-09794-8

Yoon, C. S., & Khambari, M. N. M. (2022). Design, Development, and Evaluation of the Robobug Board Game: An Unplugged Approach to Computational Thinking. *International Journal of Interactive Mobile Technologies*, *16*(6), 41–60. https://doi.org/10.3991/ijim.v16i06.26281

Yusuf, M., Yunginger, R., & Nainggolan, R. (2024). Quality of physics teaching module based on problem-based learning model integrated with PhET simulation on energy and its transformation. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 3007–3016. https://doi.org/10.29303/jppipa.v10i6.7037