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STEM education through PhET simulations: An effort to enhance students' critical thinking skills

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ABSTRACT

One of the primary purposes of physics education is to help students develop critical thinking abilities to solve everyday situations. The purpose of this research is to investigate the impact of STEM education using PhET simulation on students' critical thinking skills. A pre-experimental approach with a one-group pre-test post-test design was used in this study. There were no control or comparator groups in this study, which was done in a single group. This study was carried out in a high school in Makassar during the even semester of the 2020/2021 academic year. The research population consisted of 110 students separated into three classes. Using a simple random sampling technique, a sample of 37 students from class XI IPA2 was chosen. The results revealed a significant increase in students' critical thinking skill scores after the implementation of STEM Education using PhET simulation. The students' pre-test means score in linear motion material is 68.18, and it increased (N gain = 0.45) after STEM education through PhET simulation is applied. Likewise, the students' pre-test means score in Newton's Law material was 66.33 and rose significantly to 81.96 (N gain = 0.46) in the post-test. Therefore, this study concludes that STEM education through PhET simulations can improve students' critical thinking skills in both linear motion and Newton's laws materials. This study has implications, especially for physics teachers in improving students' critical thinking skills by using STEM education through PhET simulations.

INTRODUCTION

One of the primary purposes of science education is to prepare students to think critically while solving problems (Bancong & Song, 2020; Changwong et al., 2018). Critical thinking is important for students since it helps them to solve issues rationally in a variety of cases (Basri et al., 2019; Changwong et al., 2018) and make judgments based on relevant information and facts (Tanti et al., 2021). Critical thinking in the context of learning can provide opportunities for teachers to find out how far their students can ask questions and make reasonings (Labibah et al., 2021), and therefore critical thinking is one of the indicators that can help to enhance educational quality (Dekker, 2020; Duncan et al., 2018; Lee, 2018). Critical thinking skills refer to the ability to analyze, evaluate, and reconstruct information to make decisions and follow up on them (Labibah et al., 2021; Mahanal et al., 2019). This means that when critical thinking skills are applied in the classroom, students must critically analyze problems, evaluate solutions, and process information properly to make reasonable decisions in solving problems. Critical thinking, according to Padmanabha (2018), may be defined analytically as a

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logical discourse with rigorous and complete investigation and approach. As critical thinking abilities can assist students in efficiently dealing with challenges, they can be included in the learning process through activities and simulations (Dekker, 2020; Putranta et al., 2019).

The results of our observations in one high school in Makassar found that students' critical thinking abilities remained low. The results of our pre-test revealed that the students' critical thinking average scores in linear motion material were 68.18, while in Newton's law material, students' critical thinking score was 66.33. Several previous studies have also revealed that critical thinking skills among students in several Indonesian schools are inadequate (Permana et al., 2021; Syawaludin et al., 2019; Wilujeng & Hidayatullah, 2021). The ability to argue, the ability to judge inference, and the ability to make decisions are three indicators of critical thinking that remain low (Syawaludin et al., 2019). Students' low critical thinking skills were caused by less optimal learning strategies, models, and methods (Bustami et al., 2018; Hand et al., 2018; Linh et al., 2019). Consequently, a learning model or strategy that may help pupils enhance their critical thinking abilities is unquestionably required.

In the last four years, several studies have been conducted to investigate the impact of various models and strategies on improving students' critical thinking skills. For instance, Suyanto et al. (2021) employed a guided inquiry-based practicum approach on heat-electric energy conversion material to help students improve critical thinking skills. They stated that the practicum technique, which employs a guided inquiry paradigm, can enhance scientific behavior by strengthening students' critical thinking abilities (Suyanto et al., 2021). Besides, considering the significance of critical thinking abilities and the need for active learning by associating learning materials with real-world situations, Bustami et al. (2018) used the Contextual Teaching and Learning (CTL) model to help students enhance their critical thinking abilities. Hand et al. (2018) confirmed that teaching science in schools using the Science Writing Heuristic (SWH) approach could boost critical thinking skills. Tanti et al. (2021) also used the question-and-answer method to get students used to express their thoughts in each lesson, which helps them enhance their critical thinking skills. Interactive multimedia in physics learning was developed by Syawaludin et al. (2019) and Labibah et al. (2021). They both concluded that android-based learning media could help students improve their critical thinking skills in physics class.

A few studies have also shown that Science, Technology, Engineering, and Mathematics (STEM) education can improve students' critical thinking skills. For example, Yusuf and Widyaningsih (2019) and Perkins (2020) claimed that the use of STEM learning in the classroom could develop students' Higher Order Thinking Skills (HOTS) abilities. STEM education can be used to address issues that arise daily in the classroom, resulting in more effective learning (Alatas & Yakin, 2021). STEM education is delivered through active learning approaches that emphasize argumentation, cooperation, and problem-solving to increase students' skills while also preparing them for critical thinking (Jatmika et al., 2020; Yulkifli et al., 2022). STEM education, which has grown in popularity in the United States, was introduced in several countries in the early 2010s and drew considerable attention in the context of workforce development in science and engineering (Matsuura & Nakamura, 2021). Since the integration of subjects through the STEM approach is introduced, students' perceptions of careers in science and engineering have been more positive (Matsuura & Nakamura, 2021). Several researchers (e.g., Khatri et al., 2017) have developed teaching strategies and materials for STEM teaching in universities.

Nevertheless, schools faced some challenges in implementing STEM Education, including time management, limited equipment resources, and the Covid-19 pandemic. Teachers often try to implement STEM education within a two-hour timeframe. This limited-time can encounter frustration for both teachers and students as they are not able to complete the lesson (Linh et al., 2019). In addition, STEM education is an effort to encourage students to be actively involved in STEM practices and develop thinking habits like what scientists do (Perkins, 2020). Scientists conduct observations, formulate research questions, make predictions, and design and carry out experiments (Bancong & Putra, 2015). In addition, amid the threat of the pandemic, students and teachers are required to be able to face and adapt to online learning (Alea et al., 2020). The online learning process will be more effective when using an approach that supports the use of technology in carrying out learning (Permana et al., 2021; Safarati & Lubis, 2022).

Thus, the application of STEM education with PhET simulation is expected to be an effective solution to the problems of this study. Putranta et al. (2019) have shown that students become more enthusiastic and challenged to learn physics material because the PhET simulation is easy to operate and can be used anytime by using a smartphone, PC, or laptop. Virtual laboratories (PhET Simulation) can overcome the shortcomings observed in real laboratories. As they are allowed to behave as scientists in virtual laboratories, students can get meaning from their activities. A virtual laboratory is a simulation-based laboratory in which students manipulate objects and variables on a computer to complete experiments (Chen et al., 2014; Safarati & Lubis, 2022). Such laboratories are safer, cost-effective, clean, flexible, and time-efficient than physical experiments (Papadouris & Constantinou, 2009). During the epidemic, when some schools are obliged to provide classes online, virtual simulations are incredibly efficient. The novelty of this study is the use of a PhET simulation in conjunction with STEM education to improve students' critical thinking skills in a high school in Makassar.

The goal of this study was to see how STEM education through PhET simulation affected students' critical thinking skills. The problem is formulated as follows: 1) What is the level of students' critical thinking skills on each indicator after STEM education is implemented through PhET simulation?; 2) Is there any significant improvement in students' critical thinking skills after being taught using STEM education through PhET simulations?

METHODS

A pre-experimental research approach with a one-group pre-test post-test design was adopted in this study. There was no control or comparison group in this research, which was done in a single group. The researcher used this design due to the difficulty of determining the research subjects because the students' abilities were not homogeneous, so it was difficult to determine the comparison group. The design of this study depicts the comparison between the results obtained by the research subjects after and before being given treatment. This design is generally used to determine the effect of a treatment on the variables studied.

This design has one group that received a pre-test (O), treatment (X), and post-test. The treatment's effect was measured by comparing pre-test and post-test scores. Figure 1 below shows the research design used:

O1	X	O2

Figure 1. Pre-test and post-test research designs

This research was carried out at a Makassar City high school during the even semester of the 2020/2021 academic calendar. The research population was 110 students of class XI science, which were divided into three classes. By using simple random sampling, Class XI IPA2, which consisted of 37 students, was selected as the research sample. The average age of students was 16-17 years.

To collect data on students' critical thinking abilities, a test was developed by the research team through physics materials. The critical thinking skills test incorporates high-level cognitive processes such as interpretation, analysis, and inference through scientific approaches to solve issues (Lee, 2018; Syawaludin et al., 2019; Wilujeng & Hidayatullah, 2021). Students must compose and state their responses in their terms for critical thinking assessments (Özkan & Özaslan, 2018). The test description was adapted from Pradana et al. (2017)'s research, which investigated the development of a critical thinking ability test using optical geometry material. In this study, the topics used were linear motion and Newton's laws. The total critical thinking skills test developed was 30 items, 5 items per indicator in each material. The study instrument's validity was determined using content validity. We voluntarily invited three experts to validate the instruments used in this study. Following a content validity test, the instrument was modified based on the opinions of experts. The instrument was changed twice before the experts approved it without further changes. Table 1 shows the critical thinking indicators in the description test.

Table 1. Indicators of critical thinking skills and the number of tests in each indicator

Material	Critical thinking indicators	Item numbers
Linear Motion	Interpretation	1, 2, 12, 22, 23
	Analysis	3, 13, 14, 24, 30
	Inference	4, 5, 15, 16, 29
Newton's Law	Interpretation	6, 7, 17, 25, 26
	Analysis	8, 9, 18, 19, 27
	Inference	10, 11, 20, 21, 28

The research procedure is divided into 4 main parts. Firstly, the research subjects were given a pre-test to identify the level of their critical thinking abilities. After doing the pre-test, students were given treatment, namely STEM education through PhET simulation on the materials of linear motion and Newton's law. The implementation of STEM education via PhET simulation was carried out in approximately 8 weeks. Third, following treatment, all students were given a post-test to measure their critical thinking abilities. Finally, data analysis was carried out by comparing the post-test and pre-test scores. Data analysis was carried out using SPSS software version 25. Figure 2 depicts the flowchart of the research procedure.

Figure 2. The flowchart of the research procedure

The data analysis involved descriptive and inferential statistics. The quantitative data obtained, or students' critical thinking skills test results were analyzed using SPSS version 25. Descriptive statistical analysis included maximum scores, minimum scores, mean scores, standard deviation, variance, and N-Gain. In addition, inferential analysis was used to examine the research hypotheses, and whether there was a significant difference in students' critical thinking skills after STEM education was applied through PhET simulation. The inferential analysis used was a paired sample T-test with the test criteria: if the significance value (p) obtained is < sig. (0.05) then the hypothesis is accepted, and if the significance value (p) obtained > sig. (0.05) then the hypothesis is rejected.

RESULTS AND DISCUSSION

The results of this research demonstrated that once STEM education using PhET simulation was applied, students' critical thinking abilities improved. As can be seen in Table 2, the students' pre-test means score on the linear motion material was 68.18 and it experienced an increase (N-gain = 0.45) after the treatment. Likewise, for Newton's Law material, the mean score of the student's pre-test was 66.33 and increased significantly to 81.96 after STEM education was applied (N gain = 0.46). Table 2 summarizes the findings of a descriptive analysis of participants' critical thinking abilities scores during the implementation of STEM education using PhET simulation.

Table 2. Analysis of participants' critical thinking scores before and after the implementation of STEM education through PhET simulation.

Indicator	Linear motion		Newton's law	
	Pre-test	Post-test	Pre-test	Post-test
Maximum	75.76	92.80	83.71	92.80
Minimum	55.68	65.91	54.55	70.45
Mean	68.18	82.32	66.33	81.96
Std. Deviation	5.62	7.59	7.17	6.32
Variance	31.53	57.58	51.44	39.92
N-Gain	0.45		0.46	

As mentioned earlier, three indicators were employed in this study to assess students' critical thinking abilities: interpretation, analysis, and inference. Statistical analysis revealed that there was an improvement in students' critical thinking skills for each indicator following the introduction of STEM education through PhET simulation in teaching linear motion material. The students' scores in the interpretation indicator, as presented in Figure 3, went up significantly from 70.95 to 85.47. The same applied to the other two indicators, where the improvement reached 13.02 and 14.87 points, respectively.

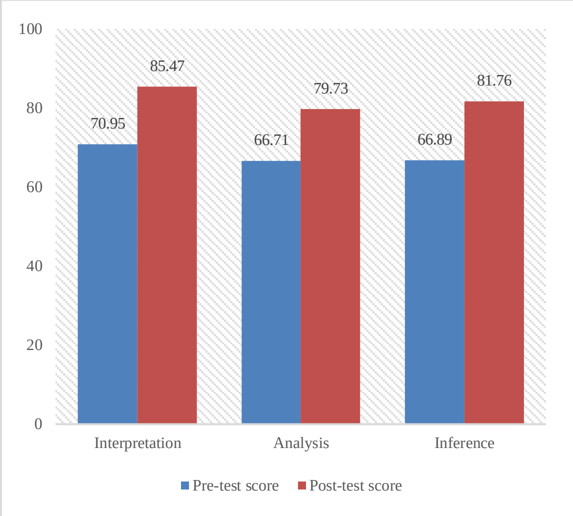

Figure 3. Students' critical thinking scores for each indicator in linear motion material

Similarly, data analysis demonstrated that students' scores in the three indicators of critical thinking skills increased significantly in Newton's law subject (see figure 4). The highest improvement obtained by the students was in the interpretation indicator namely 15.88 points, as the score increased from 70.61 to 86.49. Meanwhile, the indicator that experienced the lowest improvement was the analysis indicator, where students only scored 62.16 on the pre-test and 78.99 on the post-test.

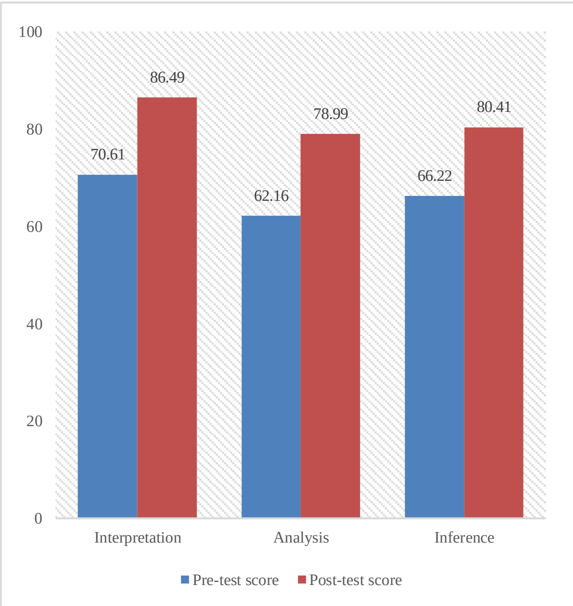

Figure 4. Students' critical thinking scores for each indicator in Newton's Law material

These results were like those in linear motion material. Finally, in the inference indicator, students' critical thinking skills increased by 13.92 points, where the post-test score was 80.41 and the pre-test was 66.22.

The paired sample T-test is utilized to answer the second study question, which is whether or not there is a significant difference in students' critical thinking skills when STEM Education is implemented through PhET simulation. The results of the analysis are reported in Figure 5.

Paired Samples Test

			Pair 1 Pre-test – Post-test
Paired Differences	Mean		-14.13838
	Std. Deviation		6.21134
	Std. Error Mean		1.02114
	95% Confidence Interval of the Difference	Lower	-16.20934
		Upper	-12.06741
t			-13.846
df			36
Significance	One-Sided p		<.001
	Two-Sided p		.000

Figure 5. Results of data analysis using the paired samples T-test in linear motion material

As shown in Figure 5, there is a statistically significant difference in the scores of students' critical thinking abilities before and after the application of STEM education through PhET simulation at a significance level of 0.05 (t = -13,846; p = 0.000). The results of this data analysis revealed that the difference between the mean scores of students' critical thinking skills on the pre-test (N = 37; M = 68.18; SD = 5.62) and post-test (N = 37; M = 82.32; SD = 7.59) was statistically significant.

Furthermore, the results of data analysis using paired samples T-Test on Newton's law material also showed that there was a statistically significant difference in students' critical thinking abilities scores before and after the implementation of STEM education through PhET simulation. Figure 6 showed that the significance value (p = 0.000) obtained is < 0.05, which means that the average score of students' critical thinking skills in the pre-test (N = 37; M = 66.33; SD = 7.17) and post-test (N = 37; M = 81.96; SD = 6.32) was statistically significant.

Paired Samples Test

			Pair 1 Pre-test – Post-test
Paired Differences	Mean		-15.63135
	Std. Deviation		5.93703
	Std. Error Mean		.97604
	95% Confidence Interval of the Difference	Lower	-17.61086
		Upper	-13.65185
t			-16.015
df			36
Significance	One-Sided p		<.001
	Two-Sided p		.000

Figure 6. Results of data analysis using the paired samples T-test in Newton's law material

The findings of this study suggest that using STEM education through PhET simulations can help students enhance their critical thinking skills. As previously stated, when STEM education was combined with PhET simulation on straight-motion material, the average score of students' critical thinking skills increased from 68.18 to 82.32. Similarly, for Newton's Law topic, the average pre-test score of the students was 66.33, which considerably increased to 81.96. Data analysis using the Paired Sample T-Test produced a significant value (p = 0.000) of 0.05 for both straight motion and Newton's laws. This suggests that there is a statistically significant difference in the critical thinking skills of students before and after the implementation of STEM education with PhET simulation.

The implementation of the STEM education approach was integrated with a problem-based learning model in this study. As a result, the learning syntax follows a problem-based learning model and is integrated with STEM. The STEM aspects are stressed in each learning session. The use of PhET simulation was carried out during the investigation's guidance stage. Students conduct experiments using PhET simulations and answer questions on student worksheets at this stage. They were then instructed to discuss the simulation experiment results with their group mates. At the stage of developing and presenting their work, each group communicates the results of their experiments with the other groups.

Discussions then ensued until they all concluded.

Based on our observations during the study, students who received the PhET simulation STEM approach were more active and ambitious to learn physics. The relevant literature has claimed that STEM education focuses on the active involvement of students so that in learning, students collaborate, exchange opinions, and carry out scientific investigations using updated tools and technology (Kennedy & Odell, 2014). Furthermore, STEM education is particularly positioned to provide children with opportunities to build thinking skills, especially critical thinking skills (Alatas & Yakin, 2021). STEM education has evolved into a meta-discipline, focusing on innovation and applied methods in developing answers to complex contextual challenges in everyday life (Khatri et al., 2017). Involving students in STEM education will be able to promote scientific inquiry and design technique processes from an early age (Jatmika et al., 2020; Yusuf & Widyaningsih, 2019). The main goal of STEM education in schools is to prepare students to continue their education at the university level and into the 21st-century workforce (Kennedy & Odell, 2014).

The findings of this study are consistent with the findings of previous research by Yusuf and Widyaningsih (2019) which found that the use of STEM education with the help of computer simulations can improve the Higher Order Thinking Skills (HOTS) ability of prospective physics teachers at the University of Papua. They also reported that prospective physics teachers had a positive perception of STEM education learning (Yusuf & Widyaningsih, 2019). Therefore, STEM-based physics learning with the help of computer simulations will continue to be developed in various topics in Physics courses to improve the HOTS abilities of prospective physics teachers (Yusuf & Widyaningsih, 2019).

The findings of this study are also corroborated by Agustina (2021), who finds that using STEM with the use of PhET simulation media on Hooke's law material can increase students' critical thinking skills. By using one group pretest-posttest design, Agustina (2021) obtained an N-gain of 0.56 and it was included in the medium category. In other words, using STEM with the help of PhET simulation media can help students develop their critical thinking abilities in the medium category. The resulting N-gains in our results are only 0.45 and 0.46, respectively. The slightly lower N-gain obtained by us in comparison to Agustina's (2021) study was owing to the smaller number of research samples. In our study, 37 pupils participated, whereas Agustina (2021) had only 10 students. With so many students, we couldn't keep track of everything. As a result, with fewer students in the class, they have more opportunities to identify physics concepts on their own when completing practicals with PhET simulations.

PhET simulations offer students a great opportunity to visualize physics concepts without having to purchase expensive physical equipment. Simulations are created in such a way that students can investigate physical laws such as Newton's second law or apply principles such as energy conservation to create the required tools (Perkins, 2020). The results of the research of Taibu et al. (2021) also concluded that the use of PhET simulations allows students to learn the necessary scientific abilities and can establish favorable attitudes toward physics. Another researcher, Putranta et al. (2019), discovered a significant boost in students' physics academic achievement after using the PhET simulation. In addition, students reported in informal interviews and responses in scientific publications that when PhET simulations were utilized in teaching, they obtained substantial learning experiences, which were distilled into three primary themes: Learning physics is enjoyable, learning physics is authentic, and learning physics is simple and straightforward (Perkins, 2020; Putranta et al., 2019).

Of course, with the shift from offline to online classes today as well as the practice of distance classroom learning, interactive simulations offer powerful pedagogical and flexible tools for teachers. Just like the scientists who build and expand their knowledge through experimentation, students can simultaneously build and expand their knowledge through exploration and discovery in interactive simulations (Perkins, 2020). Physics laboratories, according to Bancong and Putra (2015), are generally organized around five familiar steps: objectives, procedures, results, analysis, and conclusions. Unfortunately, this type of physics laboratory does not appropriately handle Bloom's cognitive taxonomy's last three steps, namely analysis, evaluation, and synthesis. Bancong and Song (2020) argued that if students carried out practicum in the traditional way, they were unable to respond to scientific inquiries, did not prioritize evidence, and did not develop evidence-based explanations. Then, the greatest solution to this problem is a virtual laboratory, which is a simulation-based laboratory in which learners manipulate objects and variables on a computer to conduct experiments (Chen et al., 2014) is the best answer to this problem. Such laboratories are safer, cleaner, more flexible, cost-effective, and time-efficient than physical experiments (Papadouris & Constantinou, 2009). During a pandemic, where some schools are teaching lectures online, virtual simulations are very effective. Thus, the results of this study can contribute to physics teachers as alternative learning to improve students' critical thinking skills using STEM education through PhET simulations.

CONCLUSION AND SUGGESTION

According to the study's findings, it can be concluded that the interpretation indicator has the greatest score on students' critical thinking, while the analysis indicator has the lowest score. Therefore, it is necessary to make efforts to improve students' analytical skills. This study also concludes that STEM Education through PhET simulation can improve students' critical thinking skills for both linear motion and Newton's laws materials.

This study has a weakness which deals with the limited number of research subjects and the absence of a comparison class. Therefore, to support the results of this study, it is suggested that future research will conduct research with a larger number of subjects and involve a comparison class. Overall, the implementation of learning will be more optimal if STEM education is associated with a virtual laboratory that provides learning simulations (PhET) as a substitute for real physics laboratories in schools.

AUTHOR CONTRIBUTION

KH and HB conceptualize ideas and prepare the design. KH presents research data and figures. HB compiled abstracts and conclusions.

REFERENCES

Agustina, F. R. (2021). Development of STEM Model Student Worksheets with PhET Simulation on Hooke’s Law Material to Improve the Ability Students’ Critical Thinking. *Journal of Physics: Conference Series*, *2110*(1), 12023.

Alatas, F., & Yakin, N. A. (2021). The Effect of Science, Technology, Engineering, and Mathematics (STEM) Learning on Students’ Problem-Solving Skill. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *6*(1), 1. https://doi.org/10.26737/jipf.v6i1.1829

Alea, L. A., Fabrea, M. F., Roldan, R. D. A., & Farooqi, A. Z. (2020). Teachers’ Covid-19 awareness, distance learning education experiences, and perceptions towards institutional readiness and challenges. *International Journal of Learning, Teaching and Educational Research*, *19*(6), 127–144.

Bancong, H., & Putra, D. P. (2015). Analisis proses keterampilan proses sains mahasiswa berdasarkan gaya berpikir dan kecerdasan jamak pada praktikum fisika modern di Universitas Muhammadiyah Makassar. *Jurnal Pendidikan Fisika*, *3*(1), 27–33.

Bancong, H., & Song, J. (2020). Exploring how students construct collaborative thought experiments during physics problem-solving activities. *Science and Education*, *29*(3), 617–645. https://doi.org/10.1007/s11191-020-00129-3

Basri, H., Purwanto, As'ari, A. R., & Sisworo. (2019). Investigating critical thinking skills of junior high school in solving a mathematical problem. *International Journal of Instruction*, *12*(3), 745–758. https://doi.org/10.29333/iji.2019.12345a

Bustami, Y., Syafruddin, D., & Afriani, R. (2018). The implementation of contextual learning to enhance biology students' critical thinking skills. *Jurnal Pendidikan IPA Indonesia*, *7*(4), 451–457. https://doi.org/10.15294/jpii.v7i4.11721

Changwong, K., Sukkamart, A., & Sisan, B. (2018). Critical thinking skill development: Analysis of a new learning management model for Thai high schools. *Journal of International Studies*, *11*(2), 37–48. https://doi.org/10.14254/2071-8330.2018/11-2/3

Chen, S., CHANG, W., LAI, C., & TSAI, C. (2014). A comparison of students' approaches to inquiry, conceptual learning, and attitudes in simulation-based and microcomputer-based laboratories. *Science Education*, *98*(5), 905–935.

Dekker, T. J. (2020). Teaching critical thinking through engagement with multiplicity. *Thinking Skills and Creativity*, *37*(May), 100701. https://doi.org/10.1016/j.tsc.2020.100701

Duncan, R. G., Chinn, C. A., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching*, *55*(7), 907–937. https://doi.org/10.1002/tea.21468

Hand, B., Shelley, M. C., Laugerman, M., Fostvedt, L., & Therrien, W. (2018). Improving critical thinking growth for disadvantaged groups within elementary school science: A randomized controlled trial using the Science Writing Heuristic approach. *Science Education*, *102*(4), 693–710. https://doi.org/10.1002/sce.21341

Jatmika, S., Lestari, S., Rahmatullah, R., Pujianto, P., & Dwandaru, W. S. B. (2020). Integrasi project based learning dalam science technology engineering and mathematics untuk meningkatkan keterampilan proses sains dalam pembelajaran fisika. *Jurnal Pendidikan Fisika Dan Keilmuan (JPFK)*, *6*(2), 107. https://doi.org/10.25273/jpfk.v6i2.8688

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging Students In STEM Education. *Science Education International*, *25*(3), 246–258.

Khatri, R., Henderson, C., Cole, R., Froyd, J. E., Friedrichsen, D., & Stanford, C. (2017). Characteristics of well-propagated teaching innovations in undergraduate STEM. *International Journal of STEM Education*, *4*(1). https://doi.org/10.1186/s40594-017-0056-5

Labibah, U. N., Mundilarto, M., & Sulaiman, S. B. (2021). Improvement of Critical Thinking Ability and Preparedness Assisted by Android-Based Media to Understand Landslide through Physics Learning. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *10*(1), 103–111. https://doi.org/10.24042/jipfalbiruni.v10i1.8221

Lee, Y. H. (2018). Scripting to enhance university students' critical thinking in flipped learning: implications of the delayed effect on science reading literacy. *Interactive Learning Environments*, *26*(5), 569–582. https://doi.org/10.1080/10494820.2017.1372483

Linh, N. Q., Duc, N. M., & Yuenyong, C. (2019). Developing critical thinking of students through STEM educational orientation program in Vietnam. *Journal of Physics: Conference Series*, *1340*(1). https://doi.org/10.1088/1742-6596/1340/1/012025

Mahanal, S., Zubaidah, S., Sumiati, I. D., Sari, T. M., & Ismirawati, N. (2019). RICOSRE: A learning model to develop critical thinking skills for students with different academic abilities. *International Journal of Instruction*, *12*(2), 417–434. https://doi.org/10.29333/iji.2019.12227a

Matsuura, T., & Nakamura, D. (2021). Trends in STEM/STEAM Education and Students' Perceptions in Japan. *Asia-Pacific Science Education*, *7*(1), 7–33. https://doi.org/10.1163/23641177-bja10022

Özkan, Y. Ö., & Özaslan, N. (2018). Student Achievement in Turkey, According to Question Types Used in PISA 2003-2012 Mathematic Literacy Tests. *International Journal of Evaluation and Research in Education*, *7*(1), 57–64.

Padmanabha, P. (2018). Critical thinking: Conceptual framework. *i-manager's Journal on Educational Psychology*, *11*(4), 45–53.

Papadouris, N., & Constantinou, C. P. (2009). A methodology for integrating computer-based learning tools in science curricula. *Journal of Curriculum Studies*, *41*(4), 521–538.

Perkins, K. (2020). Transforming STEM Learning at Scale: PhET Interactive Simulations. *Childhood Education*, *96*(4), 42–49. https://doi.org/10.1080/00094056.2020.1796451

Permana, H., Bakri, F., Salsabila, I. H., Ambarwulan, D., Muliyati, D., & Sumardani, D. (2021). The Development of Augmented Reality Application to Explore Fluid Concepts. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *7*(1), 53–60. https://doi.org/10.21009/1.07106

Pradana, S. D. S., Parno, P., & Handayanto, S. K. (2017). Pengembangan tes kemampuan berpikir kritis pada materi Optik Geometri untuk mahasiswa Fisika. *Jurnal Penelitian Dan Evaluasi Pendidikan*, *21*(1), 51–64.

Putranta, H., Jumadi, & Wilujeng, I. (2019). Physics learning by PhET simulation-assisted using problem-based learning (PBL) model to improve students' critical thinking skills in work and energy chapters in MAN 3 Sleman. *Asia-Pacific Forum on Science Learning and Teaching*, *20*(1), 1–45.

Safarati, N., & Lubis, R. H. (2022). Students' Conceptual Understanding and Critical Thinking Skills Through Online Learning Using a Virtual Laboratory. *JIPF (Jurnal Ilmu Pendidikan …*, *7*(1), 42–49. https://journal.stkipsingkawang.ac.id/index.php/JIPF/article/view/2221

Suyanto, E., Wijaya, K., Maulina, H., & Andra, D. (2021). How To Stimulate Student's Critical Thinking Skill On Learning Electrical Conversion Energy? *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *10*(1), 113–120. https://doi.org/10.24042/jipfalbiruni.v10i1.7197

Syawaludin, A., Gunarhadi, & Rintayati, P. (2019). Development of augmented reality-based interactive multimedia to improve critical thinking skills in science learning. *International Journal of Instruction*, *12*(4), 331–344. https://doi.org/10.29333/iji.2019.12421a

Taibu, R., Mataka, L., & Shekoyan, V. (2021). Using PhET simulations to improve the scientific skills and attitudes of community college students. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, 9(3), 353-370. https://doi.org/10.46328/ijemst.1214

Tanti, T., Darmaji, D., Astalini, A., Kurniawan, D. A., & Kartina, L. (2021). Critical Thinking Analysis of 13-14 Years Old Students on Lens Refraction Material. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *10*(1), 149–157. https://doi.org/10.24042/jipfalbiruni.v10i1.7119

Wilujeng, I., & Hidayatullah, Z. (2021). Alternative learning model in physics learning: Effect of the conceptual change model with cognitive conflict on critical thinking skill. *Momentum: Physics Education Journal*, *5*(2), 111–120. https://doi.org/10.21067/mpej.v5i2.5260

Yulkifli, Y., Yohandri, Y., & Azis, H. (2022). Development of physics e-module based on integrated project-based learning model with Ethno-STEM approach on smartphones for senior high school students. *Momentum: Physics Education Journal*, *6*(1), 93–103.

Yusuf, I., & Widyaningsih, S. W. (2019). HOTS profile of physical education students in STEM-based classes using PhET media. *Journal of Physics: Conference Series*, *1157*(3). https://doi.org/10.1088/1742-6596/1157/3/032021