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Combined PBL and PhET simulation for critical thinking in mathematical reasoning and problem-solving skills

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ABSTRACT

Students' critical thinking (CT) in mathematical reasoning and problem-solving (PS) skills has not developed. In fact, these skills determine achievement in society 5.0. Therefore, learning models and media are needed to develop both. This study investigated the interaction of variables in problem-based learning (PBL) combined with play mathematics with technology (PhET) simulations for CT and PS skills. This study used quasi-experimental research design using questionnaires and test of CT and PS involving 126 students of grade V of Islamic primary school (*Madrasah Ibtidaiyah* (MI)) and grade IX of Islamic junior high school (*Madrasah Tsanawiyah* (MTs)). Factorial analysis of the data used SmartPLS. Based on cross loading value, the MI level shows positive interactions on variable: "happy", "easy to use", and "as new thing" of PS skills (the explore and plan (E&P), select a strategy (SaS), and find an answer (FaA) indicators) and CT skills (the recognition of assumption (RoA) indicator). At the MTs level shows positive interaction on PS skills (the read and think (R&T) indicator) and CT skills (the inference (In) and interpretation (Int) indicators) on the "easy to use the PhET simulation" variable. Our findings highlight that combined PBL and PhET simulation has a significant relationship to develop students' CT and PS skills.

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1. INTRODUCTION

The development of science and technology in teaching and learning in the era of society 5.0 is growing rapidly in several countries [1]–[3]. In Japan, for example, the curriculum changes were carried out in accordance with social changes based on some empirical principles. Learning in Japan has begun to focus on developing student's competencies to meet the goals of the era of society 5.0, namely forming super intelligent humans [4]. In the Indonesian context, the community-based learning method 5.0 that is applied will be valuable and contribute to the effectiveness of learning.

Learning in the era of society 5.0 is facilitated through various sources, not only from books but also from various technology and information platforms [5]. The technological developments have had a profound impact on education [6]–[8] and can help teachers to become more professional [9], [10]. Technology integration and teacher competency significantly influence the development of 21st century learning [11]. Technology-based learning shows positive impacts on reasoning such as critical thinking (CT) and problem-solving (PS) skills [12], [13].

Reasoning and CT have a close relationship in the process of human thinking. Reasoning is the ability to draw conclusions based on evidence, facts, or premises available, while CT is the ability to evaluate information objectively and logically before making decisions or arranging arguments [14]. In practice, CT requires good reasoning so that a person can assess the validity of a statement, avoid the error of logic, and filter out relevant information from what is not [15]. Thus, reasoning becomes the main foundation in CT, because without proper reasoning, CT processes cannot run effectively and produce accurate conclusions.

Considering the positive effects of technology on teaching and learning, technology-based learning should be promoted to facilitate the development of skills for the society 5.0. The data from World Economic Forum (WEF) in 2025 show core skills in 2030 and are expected to continue growing rapidly such as AI and big data, reasoning (analytical thinking and creative thinking), resilience, flexibility and agility, and technological literacy [16]. CT skills in the 21st century serve as the main pillars of economic development [17], [18]. The possible challenge for teachers is to support, prepare, and develop their students to be able to face the era of society 5.0 by honing the 21st century skills, namely CT and PS skills [19]. The teacher should be able to create a learning environment that stimulates CT both inside and outside the classroom [20].

To develop mathematical reasoning especially CT skills, there needs to be learning strategies that involve students in the learning process [21], [22]. Also, CT skills can be developed effectively through PS [17]. Therefore, one alternative to CT skills in mathematical reasoning and PS skills is to implement Problem Based Learning (PBL) in the context of learning mathematics. Mercy *et al.* [23] show that in face-to-face learning, PBL is very effective in improving CT skills, especially CT. Xu *et al.* [24] and Meng *et al.* [25] show that PBL can effectively help instructors facilitate the improvement of students' PS skills. Suparman *et al.* [26] show that PBL in online learning is also very effective in improving CT. In the same vein, Almaiah *et al.* [27] show that PBL had a significantly strong positive effect in upgrading the students' CT skills. CT and PS serve as two pivotal skills that should be developed in combination through the learning process. One learning model that can improve CT and PS is PBL [14], [28]. Haji *et al.* [29] show that PBL learning could to improve the students' independent learning and understanding on mathematical concepts. Narmaditya *et al.* [30] show that the implementation of PBL also encourages students to think critically. Several studies [29], [31]–[34] on PBL and its positive impacts on learning have been carried out. While previous studies have highlighted the effectiveness of PBL in improving CT and PS skills, there have not been many studies that link PBL in collaboration with technology-based learning media, especially simulation-based games. This study; hence, investigated the interaction of play mathematics with technology (PhET) simulation in the implementation of PBL to develop students' PS and CT skills.

Technology-based learning media such as simulation games are very effective in online learning and can improve PS skills [35], [36]. Bonsu *et al.* [37] highlight this study examined the effectiveness of mobile blended learning on the academic performance of senior high school history students. Technology and mobile learning enable the use of simulation game in learning. Simulation game is interesting for student. Through simulation students can learn and explore phenomena by asking questions and seeking answers through observation simulations. Simulation game is also effective in building conceptual understanding of science and can improve CT skills, PS, and academic achievement through virtual laboratory-based learning application with physics education technology (PhET) simulation [38]–[40]. This interactive simulation of PhET can only be used in science learning (physics, chemistry, and biology) [40]. However, simulation using PhET should be made possible particularly in teaching and learning where real-life context and applications may not be always possible to conduct. The PhET simulation will facilitate students with situation enabling them to have the practical application to achieve the target competencies. As the application of PhET seems to be limited to physics, chemistry and biology, this research offers a new simulation by combining PhET to PBL to enable the application to work within the teaching and learning of mathematics named PhET.

Studies of combined PBL and PhET simulation have been carried out and show that combined PBL and PhET can improve students motivation and academic achievement [40], [41]. PhET can be an effective pedagogical tool for improving learning outcomes in science and technology education, particularly in developing countries where resources and infrastructure may be limited [42]. The three studies [40], [41], [42] however, focus more on the application of the combined PBL and PhET simulation in physics. While the study [39] has the element of mathematics in its focus, the study only focuses on the development of the worksheet for the simulation and not yet on the contribution of the combined simulation to the achievement of the PS skills. This current study hence, takes the potential of PhET to fill the scarcity of simulation in mathematics by having a combined model of PBL and PhET simulation. The Indonesian context of the

research also fit with the studies [39]–[42] that suggest further research particularly in developing countries. Therefore, in this study, we developed a virtual simulation laboratory-based learning application using the website-based unity software specifically for mathematics learning called PhET. This study investigated the interaction of variables in the PBL implementation in collaboration with PhET simulations and their contribution to students' PS and CT skills in mathematical reasoning. While earlier studies have explored the impact of PBL and PhET to CT and PS, they have not explicitly addressed its interaction on CT and PS. Combined PBL and PhET simulation integrates the syntax of PBL with PhET interactive simulation. The PhET simulation developed in this research is specifically designed for all materials in mathematics, from numbers, algebra, and geometry. Because the development of PhET simulation that carries learning material for adding fractions and number patterns has not been found in PhET simulation, it is important to examine the interaction of the variables in combined PBL and PhET simulation. The importance of testing the interactions in combined PBL and PhET simulation is to find out which variables have the biggest contribution to CT in mathematical reasoning and PS skills. Information on the interaction of these variables can be used as a reference for designing mathematics learning in the future.

2. METHOD

2.1. Research design

This research is quasi-experimental design taking the population of students of *Madrasah Ibtidaiyah* (MI) or Islamic primary schools and *Madrasah Tsanawiyah* (MTS) or Islamic junior high schools in Sidoarjo District, Indonesia. This study used quasi-experimental design or between subjects design with independent measures involving the assignment of participants to one of the experimental conditions [43]. Quasi-experiments are studies that aim to evaluate interventions but that do not use randomization [44]. This study investigated or evaluated interventions the interaction of variables in the combined PBL and PhET simulations for CT and PS skills. In the context of this study, some potential confounding variables include: i) student academic background and prior ability: differences in mathematical ability or CT levels prior to treatment may affect outcomes, regardless of the learning method used; ii) motivation and interest in learning: students with high motivation tend to have better outcomes, while students who are less motivated may not improve even when PBL and PhET are applied; iii) teacher quality and competence: teachers can vary in how they implement the combination of PBL and PhET, which can affect the effectiveness of learning; iv) access to technology: because PhET simulation is digitally based, students' limited access to or ability to use technology can affect learning outcomes; v) learning environment:the supportive (or unsupportive) classroom atmosphere or learning environment can affect students' focus and understanding; and vi) learning time: the amount of time given to implement the combination of PBL and PhET can affect the level of mastery of CT and problem-solving skills. Controlling confounding variables to increase the validity of the study, researchers can control confounding variables in several ways, such as: i) conducting a pre-test to measure initial abilities; ii) establishing a control group and an experimental group; iii) using the same learning instructions for all students; iv) conducting randomization in determining the sample; and v) ensuring the availability of adequate technology. If confounding variables are not controlled properly, the results of the study could show a biased or erroneous relationship between the PBL+PhET method and CT and problem-solving skills.

2.2. Sampling

The sample was selected through cluster random sampling technique and determined based on the material contained in the PhET interactive simulation application (fractional and polynomial material). The sample of this study was 126 students: 72 students from two classes of grade 5 and 54 students from two classes of grade 9. The subject was taken during the new normal era (post COVID-19). Therefore, the number of participants was adjusted to the government policy that schools may conduct face-to-face teaching and learning with only 50% students. Hence, the 72 and 54 students made 50% of the total students in the two grades of the schools.

2.3. Instruments

The instruments used to reveal the interaction of variables that have contributed to the implementation of PBL, the use of PhET were PS and CT tests and questionnaires for the students. PS and CT tests are based on the indicators of PS theory by Krulick and Rudnick and the Watson-Glaser Critical Thinking Appraisal (WGCTA) [45]. For the PS and CT test, there are three problems for the basic level (fractional material) and three problems for the intermediate level (polynomial). The questions on this test were adapted based on the Indonesian *Madrasah* competency assessment (AKMI) questions. Table 1 presents the grid of CT test questions and PS.

Table 1. The question grid for the test on CT and PS

Problem number	Material/competence for Islamic primary school level	Material/competence for Islamic junior high school level
1	Presented with tables and reading text on selling and buying, the students can solve contextual problems related to multiplication and fraction.	Presented with tables and reading text on traffic lights, the students can solve contextual problems related to generalization of equations from a configuration of objects.
2	Presented with reading text about visitors of *Kampung Ramadhan*, the students can solve contextual problems related to multiplication and fraction.	Presented with a configuration of objects related to ceramic installation, the student can determine the next number term.
3	Presented with reading text about habits in sports, the students can solve contextual problems related to multiplication and fraction.	Presented with a configuration of objects related to garden design planning, the student can determine the next number term.

The researchers carried out the teaching and learning according to the PBL syntax in collaboration with PhET simulation with the steps as presented in Figure 1. After the teaching and learning using PhET simulation, the students were asked to complete a CT and PS test in 30 minutes. The test was in the form of problem sheets distributed by the teacher. After the students completed the test, they were asked to respond to the online questionnaire.

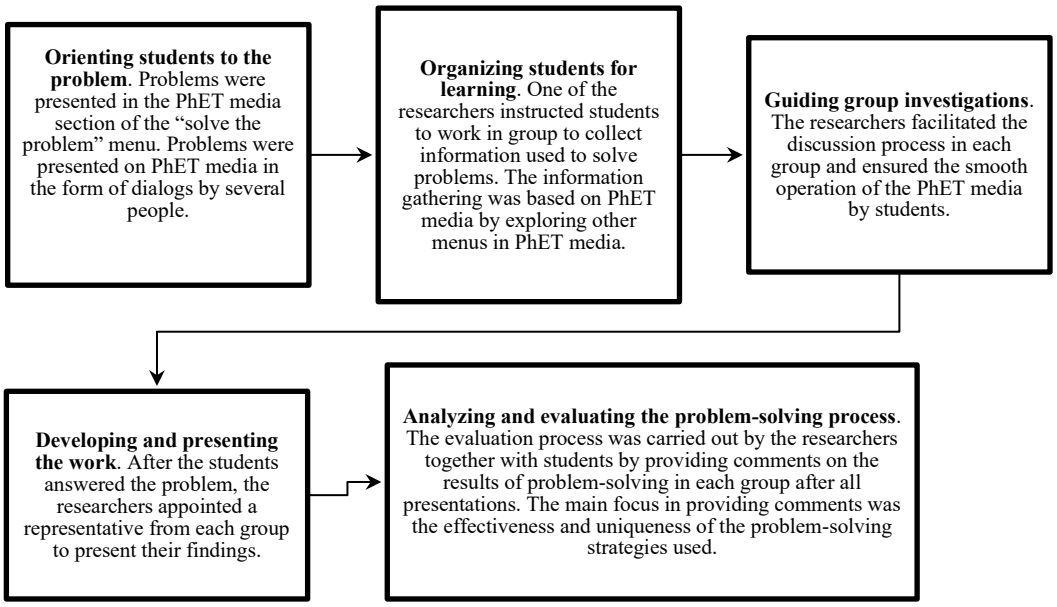

Figure 1. The syntax of PBL in combination with PhET

The closed-questionnaire has 15 questions asking the student responses on the implementation of PBL learning in collaboration with PhET. The four options variables for the response to the questionnaire include "happy", "easy to use", "content", and "as new thing". The "happy" option was used in four questions related to students' feelings during and after PBL learning in collaboration with PhET. These options of responses in the questionnaire used a Likert scale with positive and negative responses to the questions presented with four answer choices. The questions in this questionnaire were developed based on indicators of CT and PS skills. Four questions with the "easy to use" option explored students' responses related to the use of PhET. For the "content" option, there are five questions related to the delivery of material on PBL in collaboration with PhET. The remaining two questions that asked about the innovations in combined PBL and PhET simulation had the "as new thing" option. Table 2 presents the distribution of the questionnaire questions.

The results of the instrument validation show that instrument for the Islamic primary school level has the validity value between 0.786 to 0.893 with an average of 0.827, while for the Islamic junior high school level was between 0.679 to 0.929 with an average of 0.786. This means that the question items on the CT and PS test are valid. Furthermore, the results of the validation of the student response questionnaire show the validity value of 0.55 to 0.74 with an average of 0.67, meaning that the question items in the questionnaire were also valid. The results of the reliability of the test of CT and PS skills for the Islamic primary school level are 0.66 and for the Islamic junior high school level is 0.69. Meanwhile, the results of the reliability test on student response questionnaires were 0.86. This shows that the three instruments are reliable or consistent.

Table 2. The distribution of questionnaire based on the indicators of CT and PS skills

Stages of CT	Indicators of CT	Stages of PS	Indicators of PS	Number of questions
Inference (In)	Ability to differentiate the correctness and incorrectness of the information obtained	Read and think (R&T)	Rewrite the information known and asked using their own understanding	3
Recognition of assumption (RoA)	Ability to recognize the self-assumption related to the information obtained	Explore and plan (E&P)	Collect as much information as possible to assist PS using figure, graphics and tables.	3
Deduction (De)	Ability to give reasons related to the irrelevance between the information obtained and the assumption	-	-	2
Interpretation (Int)	Ability to consider the evidence of the refutation to the information given	Select a strategy (SaS)	Determine the steps to solve problems	2
-	-	Find an answer (FaA)	Formulate answer from the problem faced	2
Evaluation of arguments (EoA)	Selection of the strong and relevant arguments and their accountability	Reflect and extend (R&E)	Review the steps and solution and find the interesting things to be developed	3
		Total		15

2.4. Data collection

Data collection was carried out in semester 1 in 2 classes with the application of combined PBL and PhET simulations. The application of this learning method is based on the respective schools' policies related to limitation of face-to-face learning. At the basic level, they carried out blended learning, with 50% of students learning offline and the rest 50% having the online mode. At the secondary level, they cared out limited face-to-face learning by having two sessions with 50% students in each session. The online learning of combined PBL and PhET simulation was conducted using the Zoom meeting application. The questionnaire was distributed through Google Form whose link was provided in Zoom chat room and the classes' WhatsApp group.

The instruments were validated by nine validators (seven mathematics teachers and two lecturers of mathematics education). The validation used the Aiken formulas and the reliability test used Cronbach's Alpha via SPSS. The data analysis for CT and PS test used the following steps: i) answers of the PS questions were identified based on the indicators of CT and the PS skills (Table 2) and were scored based on the rubric, fulfilled (F), moderately fulfilled (MF), and not fulfilled (NF) as presented in Table 3; ii) the responses of questionnaire were identified based on 4 aspects of student statements and their conclusions; iii) the fulfillment of indicators was tabulated based on the results of previous identification; and iv) data from responses of questionnaire were identified and analyzed by factorial analysis using Smart partial least square (SmartPLS) 3 through two models of the outer and the inner models. The outer model was done by connecting indicator variables with latent variables, while the inner model was done by connecting latent variables to each other based on the path model of the relationship figure.

Table 3. The indicators of PS and CT

Stages	Stages and indicators of PS	Stages and indicators of CT	Category		
			Fulfilled (F)/score =3	Moderately fulfilled (MF)/score =2	Not fulfilled (NF)/score =1
1	R&T	In	Accurately state all the information known and asked for	Accurately state one of the information known and asked for	Cannot accurately state all the information known and asked for
2	E&P	RoA	Interpret the information known and accurately transfer it into figures, graphics or tables	Interpret the information known can only partially transfer it into figures, graphics or tables	Cannot at all interpret the information known and accurately transfer it into figures, graphics or tables
3	SaS	De	Accurately state the strategies used	State the strategies used but not fully accurate	State no strategies used
4	FaA	Int	Accurately explain the process to get the right answer	Explain the process to get the answer which was partially correct	No process of getting the answer
5	R&E	EoA	Review the answer and find the interesting things to develop further	Do one of the review processes or find the interesting things to develop further	Do not at all review the answer and do not find the interesting things to develop further

3. RESULTS AND DISCUSSION

3.1. Results

This research has two hypotheses on the strategy used, i.e., the combined PBL and PhET simulation, and two dependent variables, i.e., the CT and PS skills. Data presentation on the relationship between combined PBL and PhET simulation, the use of PhET simulation to develop CT and PS skills in every level of education was measured based on the achieved indicators categorized based on the type of the relationship. These categories are presented in Table 3.

The success indicators of the implementation of combined PBL and PhET simulation were: i) the students were happy with the implementation of combined PBL and PhET simulation (Happy_X); ii) the students found it easy to go through the syntax of combined PBL and PhET simulation (Easy to use_X); iii) they understand the mathematics material better (Content_X); and iv) PhET simulation is a new thing for the students (as NewThing_X). Variable X is the level of students' education.

The calculation of the attainment of each indicator of the CT and PS skills was based on the scoring grid in Table 3. Table 4 presents the result of the scoring of PS skills indicators. Table 5 presents the results of the scoring of CT skills indicators. Table 6 presents the results of the variables of the implementation of combined PBL and PhET simulation based on the Likert scale of the students' responses.

Table 4 shows that both Islamic primary and junior high school students have R&T as the highest indicators of PS skills. However, there are differences in indicators that get the lowest score on PS skills between Islamic elementary and junior high school levels. In elementary school, the two lowest scores were the "SaS" and "R&E" variables, while in junior high school the two lowest scores were the "E&P" and "R&E" variables. These scores highlight two things. First, both the elementary and junior high school students are good in reading and thinking stage of the PBL. However, the elementary school students have low skills in selecting a strategy and reflecting and extending stage. The junior high school students, in contrast, have low skills in E&P and reflecting and extending stages. Hence, both levels of schools are low in reflecting and extending stage.

As shown in Table 5, 'In' is the CT skill indicator with the highest score in both Islamic primary and junior high school levels. Despite this similar highest score at 'In' in both school levels, there are divergent variable having the lowest score. In elementary school, the lowest scores are "EoA" variables, while in junior high school the lowest scores are the "De" variables. In conclusion, that the students in both levels are good in making inferences. However, the elementary school students are lack of the skills in evaluating the arguments and the junior high school students had low scores in the De skill.

Table 4. The result of the scoring of PS skills indicator

Level	Indicators of PS skills				
	R&T	E&P	SaS	FaA	R&E
Islamic primary education	106	48	46	50	46
Islamic junior high school	72	12	60	64	12

Table 5. The result of the scoring of CT skills indicator

Level	Indicators of CT skills				
	In	RoA	De	Int	EoA
Islamic primary education	79	46	50	53	26
Islamic junior high school	76	24	8	24	20

Table 6. The result of the variable of the implementation of combined PBL and PhET simulation

Level	Variable of the implementation of combined PBL and PhET simulation			
	Happy	Easy to use	Content	As new thing
Islamic primary education	232	226	229	243
Islamic junior high school	172	166	166	168

Table 6 shows different highest and lowest scores of the variables of the implementation of combined PBL and PhET simulation. The variable "as new thing" gets the highest score in the Islamic primary school level and "happy" is the highest in the Islamic junior high school level after PBL and PhET simulation were implemented. The "easy to use" variable gets the lowest score in the elementary school level while in junior high school the lowest scores were the "easy to use" and "content" variables.

The scoring results of each indicator were used to measure the application of combined PBL and PhET simulation with aspects of achieving PS and CT skills. This can be seen from the correlation between each variable which was measured based on the value of outer loading. The aspects are reliable if they have a correlation value above 0.70. If the correlation value between these variables was below 0.70 then the related

aspects were eliminated. The elimination process continued until the outer loading value in each aspect exceeds 0.70. The aspects that meet the criteria were then tested for the construct reliability which was measured by two criteria of composite reliability (CR) and Cronbach's alpha (CA) above 0.70 [46].

Furthermore, the discriminant validity was measured by looking at the values of convergent validity and average variance extracted (AVE). The convergent validity value was measured based on the analysis of the resulting cross loading value. To meet the criteria of convergent validity, the value of cross loading on aspects of the related variables must have a higher value than the aspects of other variables. Meanwhile, the AVE for each variable at each level must exceed a minimum level of 0.500. The calculation results of CA, CR, and AVE are presented in Table 7.

The result of the construct reliability test was measured by two criteria of CR and CA as presented in Table 7. The results obtained show that there is no value below 0.70 for each variable in the CR test and the CA test. This confirms that all indicators are reliable.

Table 7. Measurement model

Variable	CR	CA	AVE
Islamic primary school level:			
PBL+PhET	0.893	0.843	0.736
PS	0.864	0.765	0.680
Mathematical CT	1.000	1.000	1.000
Islamic junior high school level:			
PBL+PhET	1.000	1.000	1.000
PS	1.000	1.000	1.000
Mathematical CT	0.901	0.781	0.82

Table 8 shows that the indicators of "happy", "easy to use", and "as new thing" in PBL+PhET was found to have a higher cross loading value when compared to CT and PS skills in Islamic primary school level. In the "explore and plan", "FaA", and "select a strategy" indicators, PS skills have a higher cross loading value than the PBL+PhET indicators and CT skills. Meanwhile, the "Recognition of Assumption" indicator on CT skills has a higher cross loading value when compared to the PBL+PhET indicator and PS skills. In Islamic junior high school level, it was found that the indicator "easy to use" in PBL+PhET has a higher cross loading value when compared to PS and CT. The indicator "read and think" and "interpretation" in PS has a higher cross loading value when compared to PBL+PhET and mathematical CT. The indicator "inference" has a higher cross loading value in CT when compared to PBL+PhET and PS.

Table 8. Cross loading value

Cross loading	PBL+PhET	PS	Mathematical CT
Islamic primary school level:			
Happy	0.880	0.423	0.556
Easy to use	0.875	0.308	0.332
As new thing	0.818	0.450	0.428
E&P	0.420	0.841	0.611
FaA	0.366	0.807	0.454
SaS	0.374	0.824	0.341
RoA	0.530	0.575	1.000
Islamic junior high school level:			
Easy to use	1.000	0.527	0.717
R&T	0.527	1.000	0.920
In	0.609	0.703	0.894
Int	0.685	0.950	0.917

As previously described, the research was conducted at two levels of education namely Islamic primary and junior high schools and is presented in the form of a factorial model that describes aspects of the related variables. The factorial model presented has been eliminated from the previous presentation. Furthermore, the structural equation model that relates the three variables is depicted in the factorial model in Figure 2. Based on the results of data processing using Smart-PLS 3 in Figure 2, the variables that meet the criteria as indicators of the implementation of PBL in combination with PhET for Islamic primary school level students are new (as NewThing_Islamic primary school), easy to use (easy to use_Islamic primary school), and happy (happy_Islamic primary school). This was obtained after having two elimination processes on indicators whose correlation value was less than 0.70.

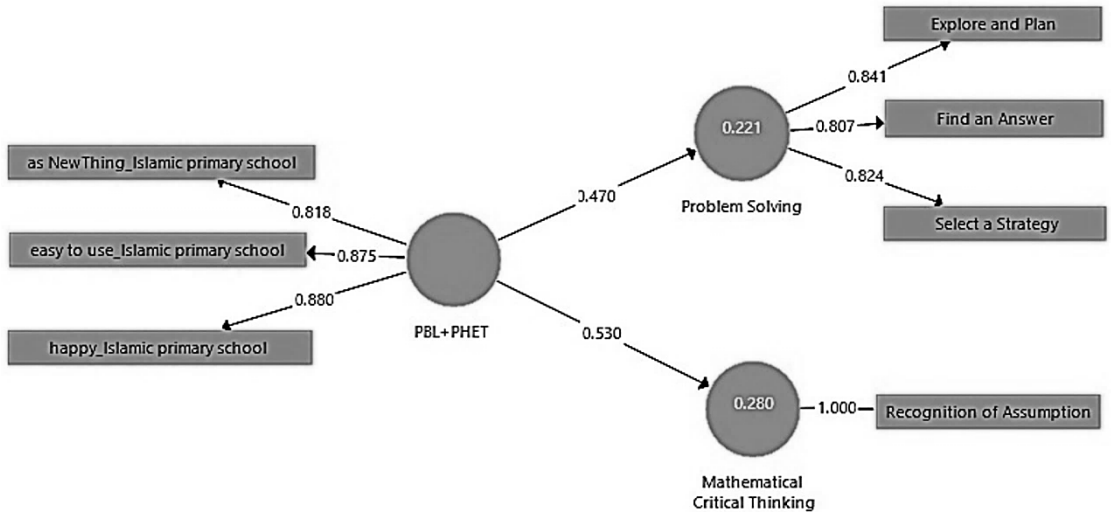

Figure 2. The relationship of the implementation of PBL in combination with PhET simulation with the CT and PS skills of the Islamic primary school students

Meanwhile, at the Islamic primary school level in Figure 3, the variable that meets the criteria as an indicator of the implementation of PBL in combination with PhET for Islamic junior high school level is easy (easy to use_Islamic junior high school). There was more elimination processes for this level compared to the process of Islamic primary school level. There were three elimination processes in the Islamic junior high school level. Further analysis shows that there is no similarity in the correlation value for each indicator.

Each variable at each level has exceeded the minimum level of 0.500. In other words, the discriminant validity of the data at each level has been met. Next, the significance level was tested through t-statistics and p-values. If the resulting t-statistic value is greater than the t-table, it is stated that there is a relationship between these variables. Furthermore, with a significant level above 0.05, the relationship between the variables is confirmed to be significant. The results of the significant level test are presented in Table 9.

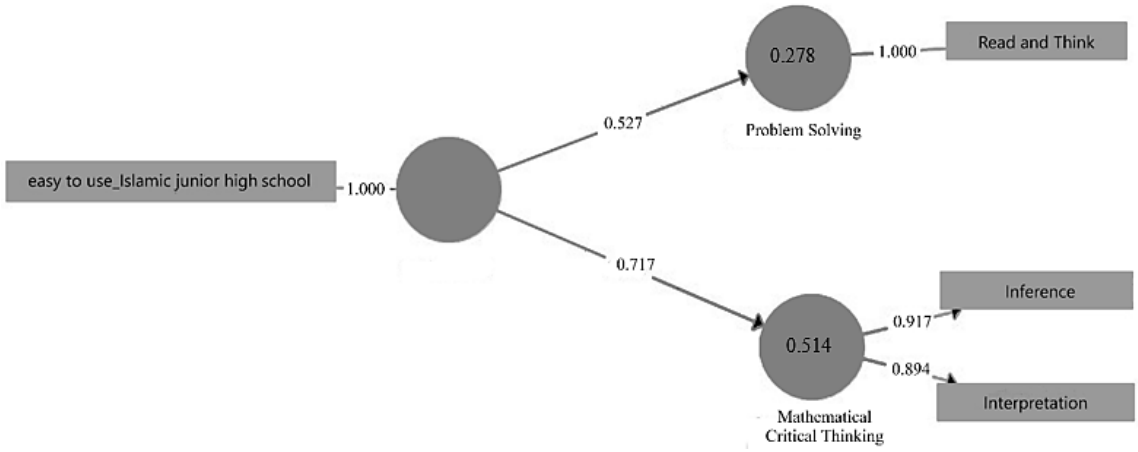

Figure 3. The relationship of the implementation of PBL in combination with PhET simulation and the PS and CT skills of the Islamic junior high school students

Further detailed analysis of the data presented in Table 9 shows that the results of the t-test on the relationship between the variables do not show the value of 0.001. We found that there is an influence between the three variables (PBL+PhET, CT, and PS). Meanwhile, the p-values are below 0.05, indicating a significant relationship between the application of combined PBL and PhET simulation to develop CT skills and PS for the Islamic primary and junior high schools. The proposed learning method in this study that is PBL tended to have an inordinately higher proportion of PS and CT skill.

Table 9. Level of significance for each level

Item	Standard deviation	t-statistic	p-values
Islamic primary school level:			
PBL+PhET→ PS	0.153	3.075	0.002
PBL+PhET→ mathematical CT	0.201	2.637	0.009
Islamic junior high school level:			
PBL+PhET→ PS	0.111	2.600	0.010
PBL+PhET→ mathematical CT	0.203	6.425	0.001

3.2. Discussion

3.2.1. Variables interaction of combined PBL and PhET in primary school

The interaction of variables that have contributed to the implementation of PBL and the use of PhET simulation on the PS skills of Islamic primary school level only occur in several related indicators. In the application of PBL in combination with PhET, the variables "as new thing", "happy", and "easy to use" show positive interactions. The greater the innovation provided results in i) higher the interest of students, ii) increased contribution to CT and PS skills, iii) better students' acceptance of the implementation of PBL in combination with PhET simulation. These results can be because a mathematics lesson is more advisable to apply innovative learning [47]. Hence, innovation in learning can be interpreted as creativity and novelty shown by teachers in changing methods and styles when delivering learning.

Most of the Islamic primary school students assessed that the combination of PBL and PhET simulation created learning that was easy to implement, especially in the operation of PhET media. This is line with the findings of Lin *et al.* [48] and Suyatna *et al.* [49] that learning media that is easy to use, even for new users, will be able to improve CT and PS skills. The accessibility of PhET simulation only through PCs but also through smartphones. Wadji *et al.* [50] explained that during the pandemic, the students at the Islamic primary school level used smartphones a lot to be able to take part in online learning well. This statement shows that Islamic primary school students are more familiar with operating smartphones than PCs. The involvement of smartphones resulted in the emergence of a sense of pleasure during the PBL learning process in combination with PhET simulation. Niromand *et al.* [51] explain that learning by using smartphones has positive influence on students' performance in the learning process. Students did not suspect that smartphones, which had only been used as a medium for conducting video conferencing in online learning, could become a learning medium containing a number of games to stimulate student's interest.

However, the variable of "content" in the aspect of the implementation of PBL in combination with PhET simulation actually gives a negative interaction on the CT and PS skills of Islamic primary school students. The variable of "content" at the Islamic primary level did not get the highest score. This is also confirmed by the results of the questionnaire showing that the "content" variable presented cannot guide students in understanding new concepts or learning materials. The students at the Islamic primary school level have very high enthusiasm in exploring the games presented on PhET media. So, with limited face-to-face learning time, they do not have time to interpret the learning materials conveyed in the application of PBL in combination with PhET media. This can be because the application of this learning is a new experience for them, considering that previous learning was only done online.

Another factor that is suspected to cause the difficulty of "content" variable to provide positive interaction of the CT skills is the difficulty to minimize the psychological and physiological factors of the Islamic primary school level students. Students of this age cannot acquire knowledge through De, or use strict logical procedures in thinking, evaluating, and learning. The implementation of PBL is combined with PhET simulation by prioritizing learning content that is not yet synchronous with the abilities possessed by Islamic primary school students. A gradual process is needed to trigger students' knowledge. The gradual process will help students to be connected to the implementation of PBL in combination with PhET simulation. These actions help students to develop CT and PS skills. This is appropriate to the condition of CT skills at the elementary school or Islamic primary school level which are still classified as very low. This finding is in line with Kolstø *et al.* [52] who shows how specific student centered teaching strategies and students' responses to these strategies contribute to a classroom culture permeated with CT practices.

Uniquely, the "read and think'' indicator on the aspect of problem-solving skills and the "inference" indicator on the aspect of CT skill did not show a positive interaction on the application of PBL in combination with PhET media, even though both indicators got the highest scores. In the "read and think" and "inference" indicators, students are required to describe and formulate problems. Meanwhile, when students cannot understand a learning material, there will be a major impact on students when asked to formulate problems related to the material. Sinnema *et al.* [53] revealed that the biggest difficulty for students in solving problems is in formulating and linking information in a problem, especially when dealing with problems of description. In other words, the negative interaction on the "read and think" and "inference"

indicators is influenced by the negative interaction on the "content" variable. When the students find the content in a learning media as difficult, they potentially have lower problem-solving and CT skills, especially in the fulfillment of these two indicators of "read and think" and "inference".

However, there are different results related to the "reflect and extend" indicator on the aspect of problem-solving skills and the "Recognition of Assumption" indicator on the aspect of the CT skills in which both have the lowest score at the Islamic primary school level. In both indicators, students are required to re-check, convey arguments, and develop problems. Studies by Siregar and Kairuddin [54] also found that only a few students' activities in solving problems could be categorized as meeting the "reflect and extend" indicator. This is complemented by the findings by Lestari *et al.* [55] in that the "recognition of assumption" indicator also gets the lowest score compared to the other four indicators. This means that students are not used to re-checking. The fact that the content of learning cannot be captured properly can be one of the causes of students not being able to convey logical arguments from the results of solving the problems at hand. So, it is not surprising that the results of this study show that the application of PBL in combination with PhET media showed a negative interaction with the indicators of "reflect and extend" and "recognition of assumption".

3.2.2. Variables interaction of combined PBL and CT in junior high school

At the Islamic junior high school level, the interaction of variables that have contributed to the implementation of PBL and the implementation of PhET simulation on students' PS skills also does not occur in all related indicators. In the application of PBL in combination with PhET, the variable "easy to use" is the only variable that shows a positive value of interaction. In fact, when reviewing the results of the student response questionnaire scoring, it is the variable "happy" that actually gets the highest score. Most of the Islamic junior high school level students assessed that the application of PBL in combination with PhET media created a pleasant learning atmosphere.

Although Miller [56] found that Islamic junior high school students who feel interested in learning materials tend to be interested in reading and trying to solve problems related to the material, the students' interest in solving problems does not necessarily become a benchmark CT and PS skills. A study by Hsu and Chen [57] found an interaction between the application of learning models, and CT. Similar results were also found by Chen and Chang [58] found that game-based learning can enhance students' intrinsic motivation, reduce cognitive load, and promote effective learning behavior in science learning. A study by Tang [59] found that digital immersive technology in educating can promote CT.

Winkler *et al*. [60] explained that learning that utilizes technology has a positive influence on increasing CT and PS skills. Currently, technology empowerment in learning is used to create more effective learning and encourage better learning outcomes. On the other hand, learning that does not apply technology will make it difficult for students to develop their abilities [20]. Therefore, the technology used should not make it difficult for students. One potential technology that already shows ease in use as found in this research is PBL in combination with PhET simulation. Findings of the study show that the implementation of the technology in this model of combination can create learning that is easy to apply, especially on the practicality of PhET media. This is because the web-based PhET media can be accessed via a PC or smartphones. So, it can be accessed anytime and anywhere. Forms of learning that can be conveniently accessed in terms of the timing will create a cooperative and collaborative learning process so that it can lead to CT processes and PS [61]. This reinforces the finding that the "easy to use" variable has a positive interaction with students' PS and CT skills even though they do not get the highest score.

Although Wardani *et al.* [62] stated that Computer Assisted Instruction (CAI)-based media allows students to carry out a repetition process to better understand the material, the "content" variable actually shows a negative interaction of students' CT and PS skills. The results of the questionnaire showed that the "content" aspect presented cannot guide students in finding solutions to a problem. The underlying factor is that the learning using PBL in combination with PhET simulation is only applied once. In fact, the application of PBL which is used as a reference in developing PS skills requires repeated treatment, not only once. This is due to students' lack of experience in solving contextual problems which become the main components in the application of PBL learning [63]. If PBL is applied several times, it will give students a habit of getting to know the characteristics of PBL for their learning.

It is not surprising that only the "read and think" indicator on the aspect of problem-solving skills and the "inference" and "interpretation" indicators on the aspect of CT skills have positive interactions on the application of combined PBL and PhET simulation. In the "read and think" and "inference" indicators, students are asked to understand and identify problems. While the "Interpretation" indicator in question is the ability to consider and assess the evidence provided and determine whether the generalization of the data can be justified. Each of these indicators can be met if students understand the problems they face. In contrast to other indicators that show negative interactions such as "FaA" on the aspect of problem-solving skills or the "evaluation of arguments" indicator on aspects of CT skills, students cannot only rely on understanding a problem but also need mastery of related concepts or materials. Of course, it is difficult to achieve mastery of

the concepts when the "content" variable in a lesson shows a negative interaction. This answers the findings in this study, that the non-positive relationship is continuous with the implementation of PBL in combination with PhET for Islamic junior high school level students.

4. CONCLUSION

Recent observations suggest that the combined PBL and PhET simulation for the Islamic primary school level has positive interactions on more diverse variables compared to the Islamic junior high school level and Islamic junior high school level. PBL in combination with PhET simulation for the Islamic primary school level shows positive interactions on three variables, namely: "happy", "easy to use", and "as new things" on problem-solving skills (especially on the E&P, SaS, and FaA indicators) and CT skills (especially on the RoA indicator). Meanwhile, at the Islamic junior high school level, there was a positive interaction in the development of problem-solving skills (especially on the R&T indicator) and CT skills (especially on the In and Int indicators) on the "Easy to use the PhET simulation" variable. Our findings provide conclusive evidence that this proposed learning method of combined PBL with PhET simulation has a significant relationship to develop mathematical CT skills and PS.

This study explored a comprehensive of interaction in PBL with PhET simulation to CT and PS skills and variables compared between Islamic primary school level and junior high school level. Further study may explore in-depth the interaction of PBL and PhET simulation to another skills (for examples: mathematical creative thinking skill, mathematics communications, and PS), and variables compared to the primary school level, junior high school level, and senior high school level. Also, future studies may explore interaction of combine PBL and PhET simulation to mathematical creative thinking skills and PS or to mathematics communication skills and PS or explore variables compared to the primary, junior high, and senior high school levels.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
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R : **R**esources
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O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

REFERENCES

[1] W. Hung and J. Sitthiworachart, "In-service teachers' conception of creativity and its relation with technology: a perspective from Thailand," *Asia-Pacific Education Researcher*, vol. 29, no. 2, pp. 137–146, 2020, doi: 10.1007/s40299-019-00460-6.

[2] V. Özdemir and N. Hekim, "Birth of industry 5.0: making sense of big data with artificial intelligence, 'the internet of things' and next-generation technology policy," *OMICS A Journal of Integrative Biology*, vol. 22, no. 1, pp. 65–76, 2018, doi: 10.1089/omi.2017.0194.

[3] J. C. Sanabria and J. Arámburo-Lizárraga, "Enhancing 21st century skills with AR: using the gradual immersion method to develop collaborative creativity," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 13, no. 2, pp. 487–501, 2017, doi: 10.12973/eurasia.2017.00627a.

[4] M. Shibata, Y. Ohtsuka, K. Okamoto, and M. Takahashi, "Toward an efficient search method to capture the future MOT curriculum based on the society 5.0," *2017 Portland International Conference on Management of Engineering and Technology (PICMET)*, pp. 1–7, 2017, doi: 10.23919/PICMET.2017.8125333.

[5] Rasmuin and D. Widiani, "Strategy and implementation of character education in era of society 5.0," in *Proceedings of the International Conference on Engineering, Technology and Social Science (ICONETOS 2020)*, 2021, pp. 575–582, doi: 10.2991/assehr.k.210421.084.

[6] H. Y. Durak, "The effects of using different tools in programming teaching of secondary school students on engagement, computational thinking and reflective thinking skills for problem solving," *Technology, Knowledge and Learning*, vol. 25, no. 1, pp. 179–195, 2020, doi: 10.1007/s10758-018-9391-y.

[7] J. F. Kiong, "The impact of technology on education: a case study of schools," *Journal of Education Review Provision*, vol. 2, no. 2, pp. 43–47, 2023, doi: 10.55885/jerp.v2i2.153.

[8] A. Haleem, M. Javaid, M. A. Qadri, and R. Suman, "Understanding the role of digital technologies in education: a review," *Sustainable Operations and Computers*, vol. 3, pp. 275–285, 2022, doi: 10.1016/j.susoc.2022.05.004.

[9] A. Bennison, M. Goos, and V. Geiger, "Utilising a research-informed instructional design approach to develop an online resource to support teacher professional learning on embedding numeracy across the curriculum," *ZDM - Mathematics Education*, vol. 52, no. 5, pp. 1017–1031, 2020, doi: 10.1007/s11858-020-01140-2.

[10] K. F. Hollebrands and H. S. Lee, "Effective design of massive open online courses for mathematics teachers to support their professional learning," *ZDM - Mathematics Education*, vol. 52, no. 5, pp. 859–875, 2020, doi: 10.1007/s11858-020-01142-0.

[11] K. A. Galeboe, R. Moalosi, Y. Rapitsenyane, and V. Ruele, "What is the impact of using design and technology pedagogy to support the attainment of 21st-century skills?" *Discover Education*, vol. 4, no. 175, pp. 1–17, 2025, doi: 10.1007/s44217-025-00604-5.

[12] S. Shanta and J. G. Wells, "T/E design based learning: assessing student critical thinking and problem solving abilities," *International Journal of Technology and Design Education*, vol. 32, no. 1, pp. 267–285, 2022, doi: 10.1007/s10798-020-09608-8.

[13] M. M. Chusni, S. Saputro, S. B. Rahardjo, and Suranto, "Student's critical thinking skills through discovery learning model using e-learning on environmental change subject matter," *European Journal of Educational Research*, vol. 10, no. 3, pp. 1123–1135, 2021, doi: 10.12973/EU-JER.10.3.1123.

[14] B. Birgili, "Creative and critical thinking skills in problem-based learning environments," *Journal of Gifted Education and Creativity*, vol. 2, no. 2, pp. 71–80, Dec. 2015, doi: 10.18200/JGEDC.2015214253.

[15] Z. A. Zulkipli, M. M. Mohd Yusof, N. Ibrahim, and S. F. Dalim, "Identifying scientific reasoning skills of science education students," *Asian Journal of University Education*, vol. 16, no. 3, pp. 275–280, 2020, doi: 10.24191/ajue.v16i3.10311.

[16] World Economic Forum, *Future of jobs report 2023*. Switzerland, 2023.

[17] K. Changwong, A. Sukkamart, and B. Sisan, "Critical thinking skill development: analysis of a new learning management model for Thai high schools," *Journal of International Studies*, vol. 11, no. 2, pp. 37–48, 2018, doi: 10.14254/2071-8330.2018/11-2/3.

[18] M. A. Küçükaydın, H. Çite, and H. Ulum, "Modelling the relationships between stem learning attitude, computational thinking, and 21st century skills in primary school," *Education and Information Technologies*, vol. 29, no. 13, pp. 16641–16659, 2024, doi: 10.1007/s10639-024-12492-7.

[19] S. C. J. Lim and M. F. Lee, "Rethinking education in the era of artificial intelligence (AI): towards future workforce competitiveness and business success," in *Emerging Technologies in Business*, A. O. J. Kwok and P.-L. Teh, Eds., Singapore: Springer Nature Singapore, 2024, pp. 151–166, doi: 10.1007/978-981-97-2211-2_7.

[20] H. C. Eren and E. K. Öztuğ, "The implementation of virtual choir recordings during distance learning," *Cypriot Journal of Educational Sciences*, vol. 15, no. 5, pp. 1117–1127, Oct. 2020, doi: 10.18844/cjes.v15i5.5159.

[21] W. A. Hazaymeh and M. K. Alomery, "The effectiveness of visual mind mapping strategy for improving English language learners' critical thinking skills and reading ability," *European Journal of Educational Research*, vol. 11, no. 1, pp. 141–150, 2022, doi: 10.12973/eu-jer.11.1.141.

[22] V. L. Akerson, I. S. Carter, M. A. P. Rogers, and K. Pongsanon, "A video-based measure of preservice teachers' abilities to predict elementary students' scientific reasoning," *International Journal of Education in Mathematics, Science and Technology*, vol. 6, no. 1, pp. 79–92, 2018, doi: 10.18404/ijemst.328335.

[23] A. Mercy, E. Lapuz, and M. N. Fulgencio, "Improving the critical thinking skills of secondary school students using problem-based learning," *International Journal of Academic Multidisciplinary Research*, vol. 4, no. 1, pp. 1–7, 2020, doi: 10.5281/zenodo.3969232.

[24] E. Xu, W. Wang, and Q. Wang, "The effectiveness of collaborative problem solving in promoting students' critical thinking: a meta-analysis based on empirical literature," *Humanities and Social Sciences Communications*, vol. 10, no. 1, pp. 1–11, 2023, doi: 10.1057/s41599-023-01508-1.

[25] N. Meng, Y. Dong, D. Roehrs, and L. Luan, "Tackle implementation challenges in project-based learning: a survey study of PBL e-learning platforms," *Educational Technology Research and Development*, vol. 71, no. 3, pp. 1179–1207, 2023, doi: 10.1007/s11423-023-10202-7.
[26] Suparman, D. Juandi, and M. Tamur, "Problem based learning for mathematical critical thinking skills : a meta-analysis," *Journal of Hunan University (Natural Sciences)*, vol. 48, no. 2, pp. 133–144, 2021.
[27] M. A. Almaiah, A. Al-Khasawneh, and A. Althunibat, "Exploring the critical challenges and factors influencing the e-learning system usage during COVID-19 pandemic," *Education and Information Technologies*, vol. 25, no. 6, pp. 5261–5280, Nov. 2020, doi: 10.1007/s10639-020-10219-y.
[28] H. Mulyanto, G. Gunarhadi, and M. Indriayu, "The effect of problem based learning model on student mathematics learning outcomes viewed from critical thinking skills," *International Journal of Educational Research Review*, vol. 3, no. 2, pp. 37–45, 2018, doi: 10.24331/ijere.408454.
[29] A. G. Haji, Safriana, and R. Safitri, "The use of problem based learning to increase students' learning independent and to investigate students' concept understanding on rotational dynamic at students of SMA Negeri 4 Banda Aceh," *Jurnal Pendidikan IPA Indonesia*, vol. 4, no. 1, pp. 67–72, 2015, doi: 10.15294/jpii.v4i1.3503.
[30] B. S. Narmaditya, D. Wulandari, and S. R. B. Sakarji, "Does problem-based learning improve critical thinking skill?" *Jurnal Cakrawala Pendidikan*, vol. 38, no. 3, Oct. 2018, doi: 10.21831/cp.v38i3.21548.
[31] L. Wijnia, G. Noordzij, L. R. Arends, R. M. J. P. Rikers, and S. M. M. Loyens, "The effects of problem-based, project-based, and case-based learning on students' motivation: a meta-analysis," *Educational Psychology Review*, vol. 36, no. 1, p. 29, Mar. 2024, doi: 10.1007/s10648-024-09864-3.
[32] G. Leggett and I. Harrington, "The impact of project based learning (PBL) on students from low socio economic statuses: a review," *International Journal of Inclusive Education*, vol. 25, no. 11. Taylor & Francis, pp. 1270–1286, 2021, doi: 10.1080/13603116.2019.1609101.
[33] K. Kwon, A. T. Ottenbreit-Leftwich, T. A. Brush, M. Jeon, and G. Yan, "Integration of problem-based learning in elementary computer science education: effects on computational thinking and attitudes," *Educational Technology Research and Development*, vol. 69, no. 5, pp. 2761–2787, 2021, doi: 10.1007/s11423-021-10034-3.
[34] J. Long, E. Dragich, and A. Saterbak, "Problem-based learning impacts students' reported learning and confidence in an undergraduate biomedical engineering course," *Biomedical Engineering Education*, vol. 2, no. 2, pp. 209–232, 2022, doi: 10.1007/s43683-022-00067-2.
[35] Iswinarti and D. R. Suminar, "Improving children's problem-solving skills through javanese traditional games," *Cakrawala Pendidikan*, vol. 38, no. 3, pp. 578–589, 2019, doi: 10.21831/cp.v38i3.25331.
[36] F. Nxumalo and W. Gitari, "Introduction to the special theme on responding to anti-blackness in science, mathematics, technology and STEM education," *Canadian Journal of Science, Mathematics and Technology Education*, vol. 21, no. 2, pp. 226–231, Jun. 2021, doi: 10.1007/s42330-021-00160-8.
[37] N. O. Bonsu, G. Boadu, B. Bervell, and J. Zagami, "Investigating the impact of mobile blended learning on history students' academic achievement," *Education and Information Technologies*, vol. 29, pp. 24783–24801, 2024, doi: 10.1007/s10639-024-12822-9.
[38] N. Rahmadita, H. Mubarok, and B. K. Prahani, "Profile of problem-based learning (PBL) model assisted by PhET to improve critical thinking skills of high school students in dynamic electrical materials," *Jurnal Penelitian Pendidikan IPA*, vol. 7, no. 4, pp. 617–624, 2021, doi: 10.29303/jppipa.v7i4.799.
[39] A. U. Kamila, R. G. Rahmawati, and Jumadi, "Development of worksheet based on STEM-PBL with PhET simulation to improve student's problem solving during the COVID-19 pandemic," in *Proceedings of the 6th International Seminar on Science Education (ISSE 2020)*, 2021, pp. 557–562, doi: 10.2991/assehr.k.210326.080.
[40] H. J. Banda and J. Nzabahimana, "The impact of physics education technology (PhET) interactive simulation-based learning on motivation and academic achievement among Malawian physics students," *Journal of Science Education and Technology*, vol. 32, no. 1, pp. 127–141, 2023, doi: 10.1007/s10956-022-10010-3.
[41] T. Dorji, S. Subba, and T. Zangmo, "De-mystifying the influence of PHET simulation on engagement, satisfaction, and academic achievement of Bhutanese students in the physics classroom," *Journal of Science Education and Technology*, vol. 33, no. 6, pp. 892–909, 2024, doi: 10.1007/s10956-024-10131-x.
[42] D. Olugbade, S. S. Oyelere, and F. J. Agbo, "Enhancing junior secondary students' learning outcomes in basic science and technology through PhET: a study in Nigeria," *Education and Information Technologies*, vol. 29, no. 11, pp. 14035–14057, 2024, doi: 10.1007/s10639-023-12391-3.
[43] H. Cham, H. Lee, and I. Migunov, "Quasi-experimental designs for causal inference: an overview," *Asia Pacific Education Review*, vol. 25, no. 3, pp. 611–627, 2024, doi: 10.1007/s12564-024-09981-2.
[44] T. Xia, F. Zhao, and R. A. Nianogo, "Interventions in hypertension: systematic review and meta-analysis of natural and quasi-experiments," *Clinical Hypertension*, vol. 28, no. 1, pp. 1–25, 2022, doi: 10.1186/s40885-022-00198-2.
[45] Riswanto, T. Heydarnejad, E. S. Dehkordi, and B. Parmadi, "Learning-oriented assessment in the classroom: the contribution of self-assessment and critical thinking to efl learners' academic engagement and self-esteem," *Language Testing in Asia*, vol. 12, no. 1, 2022, doi: 10.1186/s40468-022-00210-4.
[46] J. F. Hair, G. T. M. Hult, C. M. Ringle, M. Sarstedt, and K. O. Thiele, "Mirror, mirror on the wall: a comparative evaluation of composite-based structural equation modeling methods," *Journal of the Academy of Marketing Science*, vol. 45, no. 5, pp. 616–632, Sep. 2017, doi: 10.1007/s11747-017-0517-x.
[47] Y. A. Algani, "Innovative ways to teach mathematics: are they employed in schools?" *Journal of Computer and Education Research*, vol. 7, no. 14, pp. 496–514, Oct. 2019, doi: 10.18009/jcer.612199.
[48] S. Lin, Y. Zhou, and T. T. Wijaya, "Using Hawgent dynamic mathematics software in teaching arithmetic operation," *International Journal of Education and Learning*, vol. 2, no. 1, pp. 25–31, 2020, doi: 10.31763/ijele.v2i1.97.
[49] A. Suyatna, I. W. Distrik, K. Herlina, E. Suyanto, and D. Haryaningtias, "Developing interactive e-book of relativity theory to optimize self-directed learning and critical thinking skills," in *AIP Conference Proceedings*, 2018, doi: 10.1063/1.5054469.
[50] F. Wajdi, E. Wahyono, and A. Arif, "Management of student development on the impact of smartphones through the role of parents during the pandemic," *Journal of Educational Science and Technology (EST)*, vol. 7, no. 2, pp. 155–162, 2021, doi: 10.26858/est.v7i2.19361.
[51] E. Niromand, M. S. Mansoory, G. Ramezani, and M. R. Khazaei, "Design, implementation and evaluation of e-learning program for common diseases to smartphone-based medical students: at a developing university," *BMC Medical Education*, vol. 24, no. 1, pp. 1–8, 2024, doi: 10.1186/s12909-023-05023-4.
[52] S. D. Kolstø, V. H. P. Paulsen, and I. Mestad, "Critical thinking in the making: students' critical thinking practices in a multifaceted SSI project," *Cultural Studies of Science Education*, vol. 19, no. 4, pp. 499–530, 2024, doi: 10.1007/s11422-024-10217-3.

[53] C. Sinnema, F. Meyer, D. Le Fevre, H. Chalmers, and V. Robinson, "Educational leaders' problem-solving for educational improvement: belief validity testing in conversations," *Journal of Educational Change*, vol. 24, no. 2, pp. 133–181, 2023, doi: 10.1007/s10833-021-09437-z.
[54] B. H. Siregar and Kairuddin, "Development of students activities sheet (SAS) of linear programming based on Krulik and Rudnick problem solving to improve problem solving abilities," *Journal of Physics: Conference Series*, vol. 1462, no. 1, 2020, doi: 10.1088/1742-6596/1462/1/012029.
[55] F. P. Lestari, F. Ahmadi, and R. Rochmad, "The critical thinking ability in Watson-Glaser framework in fourth grade students," *Educational Management*, vol. 9, no. 2, pp. 234–241, 2020.
[56] J. Miller, "STEM education in the primary years to support mathematical thinking: using coding to identify mathematical structures and patterns," *ZDM - Mathematics Education*, vol. 51, no. 6, pp. 915–927, 2019, doi: 10.1007/s11858-019-01096-y.
[57] T. C. Hsu and M. S. Chen, "Effects of students using different learning approaches for learning computational thinking and ai applications," *Education and Information Technologies*, vol. 30, no. 6, pp. 7549–7571, 2025, doi: 10.1007/s10639-024-13116-w.
[58] C. H. Chen and C. L. Chang, "Effectiveness of AI-assisted game-based learning on science learning outcomes, intrinsic motivation, cognitive load, and learning behavior," *Education and Information Technologies*, vol. 29, no. 14, pp. 18621–18642, 2024, doi: 10.1007/s10639-024-12553-x.
[59] F. Tang, "Understanding the role of digital immersive technology in educating the students of English language: does it promote critical thinking and self-directed learning for achieving sustainability in education with the help of teamwork?" *BMC Psychology*, vol. 12, no. 1, pp. 1–14, 2024, doi: 10.1186/s40359-024-01636-6.
[60] R. Winkler, M. Söllner, and J. M. Leimeister, "Enhancing problem-solving skills with smart personal assistant technology," *Computers & Education*, vol. 165, p. 104148, May 2021, doi: 10.1016/j.compedu.2021.104148.
[61] D. A. Mahmudah, U. Cahyana, and A. Purwanto, "The effect of mobile learning media and scientific reasoning on creative thinking," in *AIP Conference Proceedings*, 2021, p. 040045, doi: 10.1063/5.0041910.
[62] S. Wardani, L. Lindawati, and S. B. W. Kusuma, "The development of inquiry by using android-system-based chemistry board game to improve learning outcome and critical thinking ability," *Jurnal Pendidikan IPA Indonesia*, vol. 6, no. 2, pp. 196–205, 2017, doi: 10.15294/jpii.v6i2.8360.
[63] Y. P. Xin, "The effect of a conceptual model-based approach on 'additive' word problem solving of elementary students struggling in mathematics," *ZDM - Mathematics Education*, vol. 51, no. 1, pp. 139–150, 2019, doi: 10.1007/s11858-018-1002-9.

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