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STEM-PBL Based Learning: Digital Student Worksheet Simulation aided by PhET to Improve Students' Critical Thinking Skills in Science Learning

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ABSTRACT: This study aims to develop and evaluate the validity, practicality, and effectiveness of STEM-PBL digital worksheets assisted by PhET simulation to improve critical thinking skills of junior high school students. The research design used the 4D model combined with Research and Development (R&D). The limited field test involved 10 junior high school students, while validation was conducted by 4 experts. The extensive field test with pretest-posttest design involved 94 seventh grade students from three classes. Data were collected through tests, questionnaires, and observations. Quantitative data analysis used statistical tests, while qualitative data were analyzed descriptively with percentages. The results showed that the PhET simulation-assisted STEM-PBL digital worksheet had high content and construct validity (average 0.91 and 0.97). The practicality of the worksheet was also very high (92.8%). The effectiveness is evidenced by the significant difference in N-gain (sig 0.002 <0.05) which shows a significant difference in critical thinking skills between the experimental and control classes. In conclusion, the PhET simulation-assisted STEM-PBL digital worksheet is valid, practical, and effective for density topics in science learning.

Keywords: critical thinking, digital wokrsheet, PBL, STEM.

ABSTRAK: *Penelitian ini bertujuan untuk mengembangkan dan mengevaluasi validitas, kepraktisan, serta efektivitas lembar kerja digital berbasis STEM-PBL dengan bantuan simulasi PhET untuk meningkatkan keterampilan berpikir kritis siswa SMP. Desain penelitian menggunakan model 4D yang dikombinasikan dengan metode Research and Development (R&D). Uji coba lapangan terbatas melibatkan 10 siswa SMP, sementara validasi dilakukan oleh 4 ahli. Uji lapangan luas dengan desain pretest-posttest melibatkan 94 siswa kelas VII dari tiga kelas. Data dikumpulkan melalui tes, kuesioner, dan observasi. Analisis data kuantitatif menggunakan uji statistik, sedangkan data kualitatif dianalisis secara deskriptif dengan persentase. Hasil penelitian menunjukkan bahwa lembar kerja digital berbantuan simulasi PhET memiliki validitas isi dan konstruk yang tinggi (rata-rata 0,91 dan 0,97). Kepraktisan lembar kerja juga sangat tinggi (92,8%). Efektivitasnya ditunjukkan oleh perbedaan N-gain yang signifikan (sig 0,002 < 0,05), yang menunjukkan perbedaan keterampilan berpikir kritis yang signifikan antara kelas eksperimen dan kontrol. Kesimpulannya, lembar kerja digital berbantuan simulasi PhET berbasis STEM-PBL valid, praktis, dan efektif untuk topik massa jenis dalam pembelajaran sains.*

Kata Kunci: *berpikir kritis, lembar kerja digital, PBL, STEM.*

INTRODUCTION

21st-century skills consist of critical thinking, creativity, collaboration, communication, problem-solving, and digital literacy, which are skills that students must possess (Hanipah et al., 2023; Jufriadi et al., 2022). Critical thinking is one of the skills that students must possess (I. Pursitasari et al., 2020). Critical thinking is also needed to achieve the Pancasila student profile, specifically in the critical reasoning indicator (Kemendikbud, 2022). Critical thinking also affects PISA (The Programme for International Student Assessment) results, with aspects assessed in PISA including mathematical literacy, scientific literacy, and reading literacy. In science literacy, there are indicators for critical thinking questions (Katoningsih & Sunaryo, 2020). In addition, critical thinking is very important in science learning as it influences the achievement of learning in problem-solving, investigation, and understanding the theoretical concepts of the material being taught (Astuti et al., 2021; Wibowo et al., 2024).

Critical thinking has become one of the challenges in science education (Agung et al., 2022; Darwati et al., 2021; Endaryati et al., 2021; Halimah et al., 2023). he problem of low critical thinking skills is shown in the results of PISA (The Program for International Student Assessment) in 2022, where Indonesia ranks 65th out of 79 participating countries. In 2018 Indonesia was 62nd out of 70 countries, there was a setback from the 2018 and 2022 PISA results. In the aspect of aspect of science literacy, which includes questions related to critical thinking, Indonesia ranks 67th, meaning it is still at the bottom in terms of students' critical thinking in science literacy (Kemendikbud, 2023; PISA & OECD, 2023). Various studies show that critical thinking is an issue in science education. In the study (Hayati & Setiawan, 2022) students' critical thinking is still relatively low and weak, as evidenced by test results < 50%, which is caused by students' low language and reasoning abilities. In the study (Astuti et al., 2021) Critical thinking among students post-COVID-19 pandemic is categorized as low at 56%. The students' critical thinking ability is still low, with a test result of 29%, which is caused by the learning being teacher-centered (Umam et al., 2020). Research (Ariani, 2020) shows that students overall fall into the low category with a percentage of 31.38%. Teachers tend to focus their teaching on subject content rather than on developing students' critical thinking, which shows a gap in teaching critical thinking skills in terms of innovative methods and particularly in the use of new technology (Alsaleh, 2020).

Then an observation was conducted at the junior high school to assess students' critical thinking skills, the teaching materials used, and the teachers' ability to manage the learning process. Based on the observation results, students' critical thinking skills were low in several classes, as seen from the learning process to the scores on formative tests and the lack of active learning in the classroom. Teachers still used monotonous printed teaching materials and did not employ approaches and teaching models to stimulate students to think critically.

Critical thinking is a rational and reflective thought process that focuses on deciding what to believe or do, and the cognitive and mental processes that influence someone to act in making policies and solutions based on facts (Ennis, 2011; Facione, 2011a, 2011b). Critical thinking includes components of skills such as analyzing arguments, drawing conclusions using inductive or deductive reasoning, assessment or evaluation, and making decisions or solving problems

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(Encabo-Fernández et al., 2023; Şendağ et al., 2024). To address the low critical thinking skills of students observed in the context of technological development and the 4.0 revolution, there is certainly a need for innovative teaching materials with appropriate models and approaches for student learning (Dini et al., 2024).

The problem of critical thinking in education has been addressed in a number of ways, including concept mapping, contextual learning, inquiry-based learning, and simulation-based experimentation (Distrik et al., 2024; I. D. Pursitasari et al., 2020; Resbiantoro et al., 2022). One of the solutions to address students' critical thinking is by using learning tools associated with 4.0 technology, namely digital worksheets (Dwijayanti & Soesilawati, 2022; Megahati et al., 2024; Rohmatul et al., 2024).

One kind of 21st-century learning technology is digital worksheets. Since students may access digital worksheets from anywhere at any time, they are more convenient than non-digital ones (Distrik et al., 2024). Digital worksheet components such as videos, audio, animations, and simulations make learning more engaging and interactive for students. Various research studies on the development of digital worksheets have been conducted, including digital student worksheets to enhance critical thinking (Dwijayanti & Soesilawati, 2022). Additionally, learning model-based worksheets have been created, including the problem-based learning model (Distrik et al., 2024). Digital student worksheets with a STEM approach (Agustina et al., 2021; Asrizal et al., 2023; Rahmawati et al., 2020). Because of the relationship between critical thinking and problem-based learning, digital worksheets based on problems are tools to enhance students' critical thinking skills (Siswanto et al., 2024; Umami et al., 2023). The STEM approach in science education plays a strategic role in enhancing students' critical thinking skills. This integration creates a more contextual and comprehensive science learning experience, by enabling students to make students apply scientific concepts of science with existing simulation technologies to real-world problems, fostering deeper understanding and improving their ability to analyze, evaluate, and solve complex problems. The integration of STEM in PBL not only creates contextual and meaningful learning but also equips students with essential critical thinking skills to face challenges in the modern era (Wahdaniyah et al., 2023; Widowati et al., 2021). Based on the explanation above, this research aims to create a valid, practical, and beneficial digital STEM-PBL student worksheet assisted by PhET simulations to address the problem of low critical thinking skills among junior high school students.

RESEARCH METHOD

The four stages of the 4D model define, design, develop, and disseminate are used in this study's application of the Research and Development (R&D) process (Thiagarajan, 1974). Preliminary research is carried out at the definition stage (define), which includes identifying the approach model utilized in the students' digital worksheets, creating indicators and learning objectives, and analyzing demands through theoretical and empirical studies. The design stage is carried out by designing and creating the format of the students' digital

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worksheets, preparing lesson plans, and creating research instruments. The development stage involves creating digital student worksheets for STEM-PBL using PhET simulations, followed by two experts conducting content and construct validation tests for the product. The disseminate stage is carried out to test the practicality and effectiveness of the product by conducting trials with students in experimental groups 1 and experiment 2. At this stage, the field test was carried out quasi-experimental design with nonequivalent control group design because researchers used existing groups formed naturally without any grouping again to find out the realistic results obtained later.

Table 1. Research Design

Class	Pretest	Treatment	Post test
Experiment 1 (E1)	O1	X1	O2
Experiment 2 (E2)	O1	X2	O2
Kontrol (K0	O1	-	O2

In the pilot phase, the study sample population consisted of 97 seventh grade students of SMP Negeri 11 Yogyakarta consisting of three classes. The sampling technique used random sampling by means of a random number generator by shuffling lots, consisting of two experimental classes and one control class. Learning was carried out face-to-face with the first experimental class taught by the researcher using the STEM-PBL digital worksheet assisted by PhET Simulation, the second experimental class was taught by the teacher using the STEM-PBL digital worksheet assisted by PhET Simulation, and the control class without being treated. The initial condition of all classes is that both have never learned about substance density material, so that directly the ability possessed by the substance density material in each class is the same. The flow of research design can be seen in Figure 1.

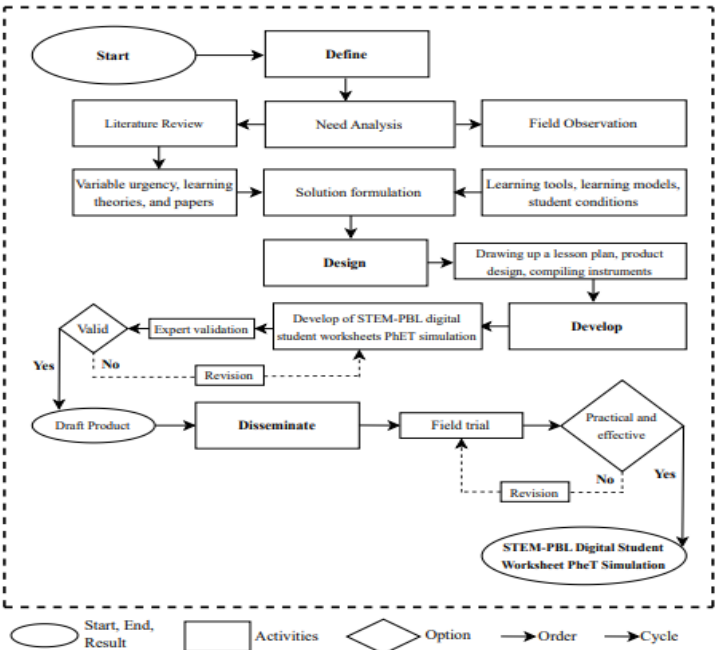

Figure 1. Flowchart of Research Design model 4D

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This research instrument consists of a questionnaire, validation sheet, observation sheet and critical thinking test instrument. Questionnaires were used to collect data on student responses to learning when using STEM-PBL digital worksheets assisted by PheT Simulation. The validation sheet is used to validate the product and critical thinking test instrument. Observation sheet to observe the initial conditions of learning student needs and learning implementation. Practicality data is obtained from filling out instruments from teachers and implementation and student responses to learning. Critical thinking test with five indicators synthesized from (Ennis, 2011; Facione, 2011a, 2011b) namely interpretation, analysis, evaluation, explanation, and conclusion who used critical thinking instruments from research (Ikhsan, et al. 2025).

The observation sheet for the implementation of learning, student response questionnaire, and teacher practicality validation sheet are used to assess the practicality of the product which in this study adapted instruments from research (Buhera, et al. 2024). Learning implementation data based on observation sheets with a dichotomous rating scale of agree and disagree, student responses on a dichotomous rating scale of agree and disagree, and practicality validation with a Likert scale are all analyzed descriptively, namely grouping data and categorizing low, medium or high implementation. The effectiveness of STEM-PBL digital worksheets assisted by PheT Simulation between experimental and control classes with the results of normality data for experimental class one 0.000, experimental class two 0.003 and control class 0.001, so that <0.05 is abnormal. Then the results of homogeneity data are 0.06, so > 0.05, which is homogeneous. Because the prerequisites do not meet so use non-parametric tests using the kruskal-wallis test then the mann-whitney u test on the N-gain of students' critical thinking.

The independent sample Mann-Whitney test was used to examine the difference in N-gain of students' critical thinking between the experimental and control classes. Normalized gain was used to interpret the computation results based categories (Meltzer, 2002) because n-gain, according to Meltzer, has the ability to provide a clearer picture of changes in student learning outcomes after an intervention on the table 2.

Table 2. N-Gain Value Categories

Normalized N-Gain	**Category**
g > 0,7	High
0,3 < g $\leq 0{,}7$	Medium
g < 0,3	Low

Validators of STEM-PBL student digital worksheets by four experts, namely media experts, material experts and two practitioners who were then analyzed with the Aiken's V equation can be seen in the equation 1:

$$V = \frac{\sum s}{(n(c-1))}$$

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Description: V = rater agreement index, s = the score given by each rater minus the lowest score in the category used (s = r - Io) r = the score of the category chosen by the rater, Io = the lowest score in the assessment category, n = number of raters c = number of categories chosen by the rater. The results of the validation of the worksheets developed are divided into three categories as in table 4 (Retnawati, 2016).

Table 3. Aiken's V categories

Score of Aikens'V	Category
V > 0.8	High
0.4 ≤ V ≤ 0.8	Medium
V < 0.4	Low

Seeing the practicality of the worksheet developed is by distributing a reposn questionnaire to 10 students using a purpose sampling technique based on the level of student ability based on the results of formative tests in each class. Then analyzed using equation 2.

$$P = \frac{\sum X}{\sum X_i}$$

Description: P = percentage of practicality, ∑X = score obtained, ∑Xi = maximum score. Categorization of the practicality of the developed digital worksheets, as in table 4 (Dewi et al., 2022).

Table 4. Category of Practicality Score

Practicality Score (%)	Category
85 < P ≤ 100	Very Practical
70 < V ≤ 85	Practical
55 < P ≤ 70	Practical Enough
40 < P ≤ 55	Less Practical
0 < P ≤ 40	No Practical

The material used is the density of substances. The problem addressed in the PBL model is that some students experienced when drinking tea, then placing bread on top of the tea, the bread sank while the plastic did not. They were confused about why this happened. The answer to these problems is certainly to use PheT simulation with stages, namely preparation before using PheT (introduction to concepts, learning objectives), guidance in starting the simulation (initial instructions, initial exploration), simulation implementation (step instructions, observation and recording, structured experiments), discussion, further investigation (advanced experiments, application of concepts), evaluation and assessment (individual assignment quizzes). For the PBL steps, the explanation of STEM and the STEM-PBL relationship in the research can be seen in Table 5.

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Table 5. Steps of PBL, STEM, STEM-PBL

Problem Based Learning (PBL)	Science, Technology, Engineering, Mathematics (STEM)	STEM-PBL
Problem Orientation	Science: Learning materials	Problem orientation - Science
Learning Organization	Technology, Engineering: PheT simulation	Learning Organization - Engineering and Technology
Investigation	Mathematics: Calculation of density, volume	Investigation - Mathematics
Development		
Analysis and Evaluation		

RESULT AND DISCUSSION

Result

The STEM-PBL student digital worksheets assisted by PhET Simulation have proven to be valid, practical, and effective. The validation of the digital worksheets consists of construct and content validation. The content validation components include the feasibility of the content or material, alignment with the PBL model, and the STEM approach. The construct validation components include the feasibility of presentation, language feasibility, and virtual practicum feasibility. The results of the content validation are in Table 6.

Table 6. Validity of the Content of STEM-PBL Digital Worksheets Assisted by PhET Simulation

No	Aspect	Validator				Aikens Index	Category
		1	2	3	4		
1	Content or material eligibility	4	4	4	3	0,92	High
2	Conformity with PBL model	4	4	4	4	1	High
3	Suitability of STEM approach	4	3	3	4	0,83	High
Overall Average						**0,91**	**High**

Table 6 shows that the STEM-PBL student digital worksheet assisted by PhET Simulation has an overall average score of 0.91 with a high category in terms of content from two validators and two practitioners. In the aspect of the suitability of the STEM approach, there are several comments from the validators, namely on the engineering content which is still weak, only linking it to the technique of substance density on the PhET simulation. This is in line with research on the causes of the low suitability of learning materials with STEM engineering content, namely due to integration between disciplines, as well as the application of these concepts in inappropriate engineering practices. Construct validation results in table 7.

Table 7. Validity of the construct Digital STEM-PBL Worksheets Assisted by PhET Simulation

Corresponding author: Muhammad Ikhsan (mikhsan17821@gmail.com)

No	Aspect	Validator				Aikens Index	Category
		1	2	3	4		
1	Presentation eligibility	3	4	4	4	0,92	High
2	Language proficiency	4	4	4	4	1	High
3	Eligibility for virtual internships	4	4	4	4	1	High
Overall Average						**0,97**	**High**

Table 7 shows that the digital worksheets for STEM-PBL students assisted by PhET Simulation have an overall average score of 0.97 with a high category across three aspects of the construct from two validators and two practitioners, making them suitable to continue in the research. The results of this research development are in the form of digital student worksheets for STEM-PBL assisted by PhET Simulation on the topic of material density for seventh grade, developed using the 4D model as follows.

Discussion

The first stage is define. At this stage, the researcher conducts an initial needs analysis, starting with a literature review on critical thinking variables, followed by observations and interviews with science teachers at the school related to student analysis, teaching materials analysis, and learning analysis. The results of observations and interviews with science teachers at the school show that the teaching materials frequently used in lessons are printed books and printed worksheets. The use of electronic teaching materials is rarely utilized, and the use of PhET simulations is never incorporated into the lessons. The condition of students' critical thinking is still very low, as seen from the results of the formative tests.

Learning analysis is conducted by analyzing the ongoing topic in the learning process, which is the topic of matter and substances. Therefore, the next topic is the density of substances. In the learning process, there has been no use of the PBL model and the STEM approach. Next, the learning outcomes and objectives for the topic of substance density are determined. The learning objectives in the STEM-PBL digital worksheet assisted by PhET simulation are as follows: a) Finding solutions related to determining the density of objects; b) Identifying the name of a substance through the concept of substance density; c) Understanding the concepts of floating, sinking, and submerged objects.

The second stage of design. This stage includes the learning plan, product design, and instrument development. The learning plan is created for only one complete session. The product design is made according to the analysis needs that have been conducted. The first product design can be seen in Figure 2. The developed instruments include media expert instruments, material expert instruments, in this study the researcher adopts instruments from the research (Distrik et al., 2024; Septajati & Widowati, 2024) and for the critical thinking variable instrument, which is a test with five objective questions containing indicators, in this study the researcher adopted the instrument from the research (Imran et al., 2022; Rohmatul et al., 2024; Siswanto et al., 2024).

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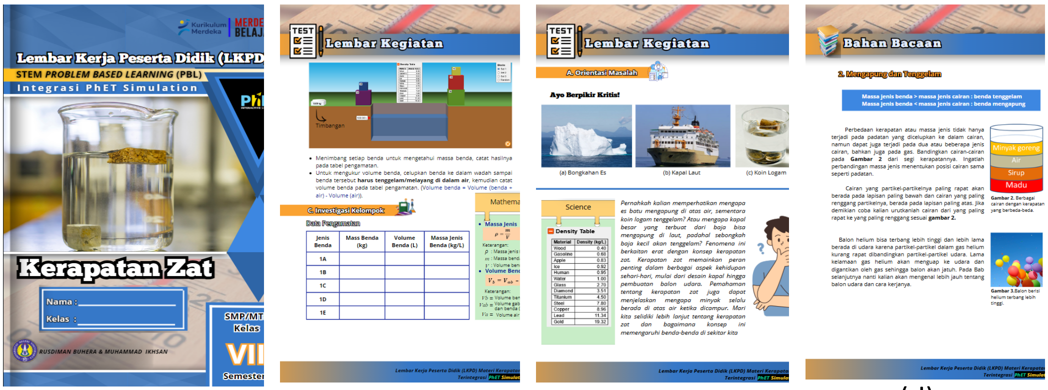

(a) (b) (c) (d)

Figure 2. Cover (a), Content (b,c,d)

The third stage is development. This stage involves evaluation by validators, including subject matter experts, media experts, and two teacher practitioners, who will provide comments and suggestions on the feasibility of the STEM-PBL digital worksheets assisted by PhET simulations. If there are comments and suggestions, the researcher will make revisions and then conduct a practicality test.

The fourth stage is disseminate. This stage is the dissemination phase of the final product, the digital STEM-PBL worksheets assisted by PhET simulations on the topic of material density for seventh grade. Based on tables 6 and 7, the results are suitable for implementing the digital STEM-PBL worksheets assisted by PhET simulations in learning using the predetermined steps. Students responded positively to the practicality of the STEM-PBL digital worksheet assisted by PhET simulation. In practicality, there are five aspects: ease of instructions and use consisting of four questions, clarity of instructions and guidelines consisting of five questions, effective integration of PhET simulations consisting of six questions, support for independent learning consisting of six questions, and alignment with students' needs consisting of five questions. The practicality questionnaire responses (Table 8) from students were in the form of a dichotomous questionnaire with agree and disagree answers (Daliyah, 2020).

Table 8. The Practicality of Student Responses to Digital STEM-PBL Worksheets Assisted by PhET Simulations

Aspect	Number of Questions	Maximum Score	Score obtained	Practicality Score %	Category
Ease of instruction and use	4	40	38	95	Very Practical
Clarity of instructions and guidance	5	50	47	94	Very Practical
Effective integration of PhET simulation	6	60	56	93	Very Practical

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Self-directed learning support	6	60	55	92	Very Practical
Suitability to the needs of students	5	50	45	90	Very Practical
Overall Average				**92,8**	**Very Practical**

The practicality of the STEM-PBL digital worksheet assisted by PhET simulation showed an overall result of 92.8% in the very practical category. Students who filled out the practicality questionnaire were students who obtained the highest posttest results, namely 10 students. Student responses that support this category indicate that they feel very helped and satisfied with the application of simulation in the context of learning. Some aspects that support the very practical category through several student responses are the ease of applying concepts to the real world, speed in gaining deep understanding, independence in exploration and learning, ability to use effective simulations in problem solving, clearer understanding and interactivity in learning satisfaction. Table 9 displays the pretest and posttest results of the experimental and control classes for critical thinking.

Table 9. Results of Pretest and Posttest Critical Thinking for Experimental Class and Control Class

Class	Test	Interpre-tation	Analys-is	Evalua-tion	Explan-ing	Conclu-sin	Average
E1	Pretest	15	18	17	15	12	**2,33**
	Postest	23	26	26	21	23	**3,60**
E2	Pretest	15	11	12	7	11	**1,80**
	Postest	22	21	20	16	19	**3,16**
K	Pretest	13	11	11	12	9	**1,86**
	Postest	18	16	15	15	16	**2,66**

Students' critical thinking is categorized as low in the experimental class 1, experimental class 2, and control class. Experimental classes 1 and 2 showed an improvement in conceptual understanding after learning using STEM-PBL digital worksheets assisted by PhET simulations. Table 9 shows the pretest and posttest results for each indicator, namely interpretation, analysis, evaluation, explanation, and conclusion. Most students had problems with critical thinking in the density of matter material before the lesson. Students had difficulty with critical thinking because the material presented was purely theoretical, without starting with contextual problems in everyday life, so students were unable to think critically and could only understand the theory. The problem of students' critical thinking was addressed by using digital STEM-PBL worksheets assisted by PhET simulations. To see the increase in critical thinking N-gain in Figure 3.

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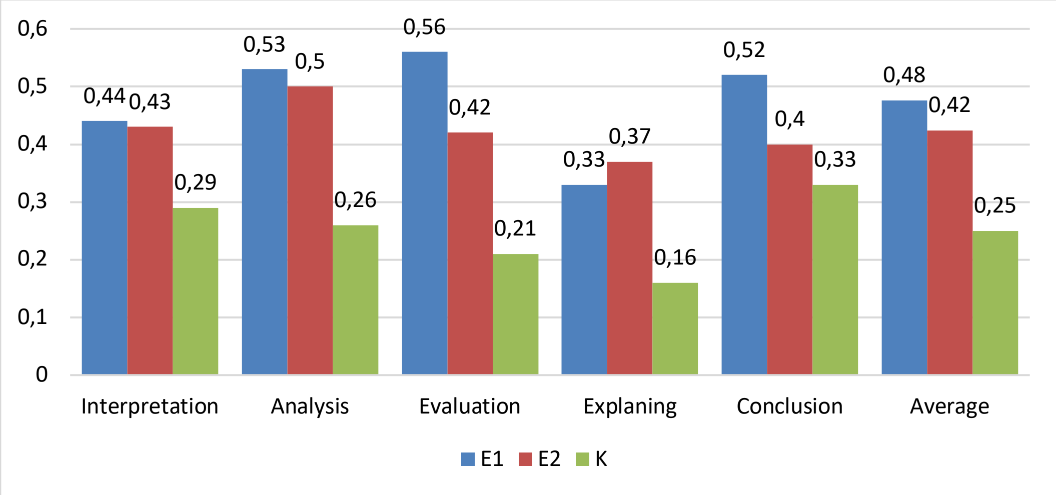

Figure 3. N-gain Critical Thinking Indicator for Experimental Class 1, Experimental Class 2, and Control Class

The n-gain results for each of the experimental class 1, experimental class 2, and control class indicators are displayed in Figure 3. N-gain Class 1's interpretation indicator falls into the moderate category, Class 2's falls into the moderate category, and the control class falls into the low category. The control class falls into the low category, experiment class 2 falls into the moderate category, and experiment class 1's N-gain Analysis Indicator falls into the moderate group. The control class falls into the low category, experiment class 2 falls into the moderate category, and experiment class 1's N-gain Evaluation Indicator falls into the moderate group. N-gain Explanation Indicator for experiment class 1 is in the moderate category, experiment class 2 is in the moderate category, and control class is in the low category. N-gain Conclusion Indicator for experiment class 1 is in the moderate category, experiment class 2 is in the moderate category, and control class is in the low category. The overall average N-gain for experiment class 1 is 0.48 (moderate category), experiment class 2 is 0.42 (moderate category), and control class is 0.25 (low category). There are differences between experiment class 1, experiment class 2, and the control class. The highest N-gain was in the experimental class 1. This is because the STEM-PBL digital worksheets assisted by PhET simulations were used in teaching by the teacher who implemented them, allowing the teacher to better understand the characteristics of the students (Safitri et al., 2022) resulting in higher scores compared to the experimental class 2 and the control class. The control class had lower scores due to the absence of treatment using the STEM-PBL digital worksheets assisted by PhET simulations. This indicates that the developed STEM-PBL digital worksheets assisted by PhET simulations have an impact on students' critical thinking. The results of the Kruskal-Wallis independent sample test between the three classes' N-gain critical thinking are shown in table 10.

Table 10. Results of the Kruskal-Wallis independent sample N-gain critical thinking test

Aspect	Class	N-gain	Category	Kruskal-Wallis

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Critical Thinking	E1	0,48	Medium	0,002
	E2	0,42	Medium	
	K	0,25	Low	

The Kruskal-Wallis results for the difference in N-gain critical thinking between experimental classes 1 and 2 as well as the control class are shown in Table 10. A sig value of 0.002 < 0.05 indicates that H0 is accepted, indicating a significant difference in critical thinking between experimental classes 1 and 2. These findings suggest that students' critical thinking skills regarding matter density in scientific education are improved by the STEM-PBL digital worksheets that are aided by PhET simulations during the learning process. This is consistent with previous research, which showed that student worksheets in physics based on ethnoscience using the discovery learning and guided inquiry models can improve students' critical thinking skills (Ananda & IF Tanjung, 2022; Ramli et al., 2020; Septiaahmad et al., 2020). PBL-based student worksheets show that they can enhance students' critical thinking, as the presence of problems requires students to think critically to find solutions in learning (Elfina & I Sylvia, 2020). From several previous studies, there has been no collaboration between STEM-PBL on digital worksheets assisted by PhET simulations that can enhance students' critical thinking in science learning. The results of the Mann-Whitney independent sample test (Table 11) to see the influence between two classes, whether there is a difference or not.

Table 11. Results of the Kruskal-Wallis independent sample N-gain critical thinking test

Class	Mann-Whitney
E1 - K	0,000
E2 - K	0,109
E1 - E2	0,153

Table 11 shows the results of the Mann-Whitney test between the experimental class 1 and the control class with an Asymp Sig (2-tailed) value of 0.000 < 0.05, thus H0 is rejected, indicating a difference between the experimental class 1 and the control class. These results indicate that the treatment given to experimental class 1 has a significant and effective impact in producing changes compared to the control class, which did not receive any treatment. Experimental class 1 is the class that received the treatment and was conducted by the teacher in their teaching.

The results of the Mann-Whitney test between the experimental class 2 and the control class showed an Asymp Sig (2-tailed) value of 0.109 > 0.05, thus H0 is accepted, indicating no difference between the experimental class 2 and the control class. This result indicates that there is no significant difference between the two classes. In other words, the treatment given to the experimental class 2 has not yet been able to provide a statistically significant difference compared to the control class. Class Experiment 2 is the class that was treated and conducted

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by the researcher themselves. This is due to several factors such as the less effective way of managing learning by the researcher and the fact that the experimental class 2 is a class with a low level of learning outcomes. This is in line with the research (A. Wibowo, 2017) the presence or absence of a significant difference between the research experimental class and the control class.

The results of the Mann-Whitney test between experimental class 1 and experimental class 2 showed an Asymp Sig (2-tailed) value of 0.153 > 0.05, thus H0 is accepted, indicating no difference between experimental class 1 and experimental class 2. This result shows that there is no significant difference between the two experimental classes. Although experimental class 1 showed a significant difference with the control class, its effectiveness is not statistically different from experimental class 2.

The results of the Mann-Whitney test are a non-parametric statistic used to compare differences between two independent groups when the data is not normally distributed (Janna, 2020; Wulansari, 2023). In the results of this Mann-Whitney test, it shows a significant influence that the treatment applied to experimental class 1 proved to be the most effective in providing a different effect compared to the control condition. However, it should be considered that although the treatment in the experimental class 2 did not show a significant difference from the control class, it does not mean that the treatment had no effect at all. This is because in the experimental class 1, the treatment was given by the teacher, while in the experimental class 2, the treatment was given by the researcher. This certainly affects the results, as the teacher understands the characteristics of classroom management better than the researcher (Liang et al., 2024; Mustajab & Sutarni, 2024). According to (Mesra et al., 2023) development research in education is most effective when field trials are conducted by teachers who implement it in learning, not by researchers. This is because the concept in development research is to create a product, and the one testing it is the teacher in the school.

Further research is recommended to conduct a more in-depth analysis of the factors that may influence the effectiveness of the treatment, especially in the Experiment 2 group. Additionally, modifications or refinements to the treatment method can also be considered to achieve more optimal results.

CONCLUSION

This research demonstrates that the STEM-PBL digital worksheets, enhanced with PhET simulations, show promise in terms of validity, practicality, and effectiveness for teaching the concept of density to seventh-grade students within the specific context of Junior High School 11 Yogyakarta. Content validity, assessed by four experts (media experts, material experts, and two practitioners) using Aiken's V, yielded a high average score of 0.91, indicating strong alignment with learning objectives, accurate content, clear instructions, and appropriate use of PhET simulations. Construct validity also resulted in a high average score of 0.97. Practicality was evaluated through questionnaires administered to ten students, selected via purposive sampling, focusing on ease of use, clarity,

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engagement, and the perceived helpfulness of the simulations. The average practicality score of 92.8% falls into the "Very Practical" category, suggesting high student acceptance and usability. Effectiveness was determined by comparing N-gain scores across two experimental groups and one control group. A Kruskal-Wallis test revealed a statistically significant difference (sig 0.002 < 0.05). Post hoc Mann-Whitney U tests indicated significant differences between each experimental group and the control group ($p < 0.05$), but no significant difference between the two experimental groups themselves. The N-gain values for the experimental groups were in the medium category ($0.3 < g \leq 0.7$), while the control group was in the low category ($g < 0.3$). While a formal effect size (Cohen's d) wasn't calculated in the original manuscript, the observed differences in N-gain suggest a potentially meaningful impact on student learning. It's important to acknowledge that these findings are specific to the sample and setting of this study. Further research with larger, more diverse samples is needed to determine the generalizability of these results and to investigate the worksheets' long-term impact on critical thinking skills beyond the topic of density.

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