

Integrating Virtual Laboratory through Designing Worksheets STEM-PBL to Improve Students' Problem-Solving Skills in Junior High School

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Abstract. Problem-solving skills are crucial in the modern era, so they become essential in increasing power competitiveness and adaptability. Research This aims to develop a virtual laboratory-integrated STEM-PBL worksheet. This research employs the research and development methodology using a 4D model. The validators consist of 4 media experts, content experts, and two practitioners. The readability test used 10 students selected from class VII by purposive sampling based on academic ability. This research shows that the STEM-PBL worksheet integrated with the virtual laboratory can increase students' problem-solving skills. Validation results show that all worksheet aspects are categorized as high with Aiken's Index value between 0.83-1.00. The practicality test of the worksheet obtained very practical category with a range value of 90-95% in all Implementation aspects of the worksheet, shows improving students' problem-solving skills with an overall N-gain of 0.51 (medium category), where improvement occurred in the solution implementation indicator (N-gain 0.70) and the lowest in solution evaluation" (N-gain 0.25). The effectiveness of the worksheet is proven through the Wilcoxon signed rank test, which shows a significant difference in students' problem-solving skills before and after treatment ($p < 0.05$).

Keywords: Problem-solving skills, STEM-PBL, worksheet, virtual laboratory,

Introduction

In the current educational context, problem-solving skills (PSS) are becoming increasingly important, particularly in this era of Industry 4.0. Students must develop the capability to tackle the complex challenges that emerge both in their daily lives and in their future professional careers (Hendriani et al., 2021; Hizqiyah et al., 2022). PSS are very relevant to science learning, where students must be able to analyze and solve problems related to natural phenomena (Silvianti et al., 2022; Chaerunisa & Pitorini, 2022). Students who have good PSS will adapt more quickly to changes in the environment (Albert, 2020),

improve their quality of life and ability to interact (Farid et al., 2020), and prepare students to face the 21st century (Kayati et al., 2023). Students who are involved in problem-solving will later improve their critical and creative thinking skills (Suharyat et al., 2023).

Previous studies have shown that the typical or mean ability of junior high school students to solve problems in their science studies, namely the average PSS at SMPN 1 Petarukan, Pemalang Regency, got a score of 43.42% with sufficient criteria (Andika & Siswanto, 2020). The average PSS at MTs Asnawiyah, Bogor Regency is 15.2% with a very low category (Rahayu et al., 2021). The average PSS at SMP Negeri 2 Pinoh Selatan and SMP Kristen Ekklesia Nanga Pinoh 2, Melawi Regency, which is 24.68%, are still very low (Permatasari et al., 2024). The average PSS at SMPIT Al-Ghozali Jember is 24.9%, with a very low category (Amala & Yushardi, 2022). Multiple research findings show that students' ability to solve problems in science subjects at the junior high school level is low on average.

Several interrelated factors cause low PSS among students in science learning. Students are not accustomed to applying science concepts in real situations, so they have difficulty using the knowledge they have learned (Ainy et al., 2024; Swiyadnya et al., 2021), lack of student interest in reading teaching materials (Sukma & Handayani, 2022), use of monotonous and less innovative learning media (Wawat, 2022). The use of ineffective learning methods and lack of student involvement in the learning process (Trimayora et al., 2021; Anggraini et al., 2021). As well as the lack of variation in learning models used in science learning (Tanjung et al., 2018).

The implementation of more active learning models, such as problem-based learning (PBL), can increase student engagement and help them enhance and cultivate critical and creative thinking abilities that are essential for solving problems (Widura et al., 2021). This learning model not only improves PSS but also motivates students to take ownership of their learning and participate actively in class (Astuti et al., 2022; Firdaus & Mukhaiyar, 2021), substantially enhances problem-solving capabilities compared to traditional learning methods (Zunanda & Sinulingga, 2015), students are trained to identify problems, plan strategies, and apply their knowledge to find solutions (Marini et al., 2022; Suhartono, 2018).

A relevant approach is STEM-based learning. STEM-based learning can improve the perception of 21st-century skills and PSS (Koculu et al., 2022; Alan et al., 2019). Learning models based on PBL that incorporate scientific investigation methods have been shown to enhance students' abilities to solve problems effectively (Gültekin & Altun, 2022). The application of the STEM-PBL model has a more significant effect on improving PSS compared to conventional learning models (Parno et al., 2019). Thus, the application of innovative learning models such as PBL and STEM is very important in the context of science learning.

Student worksheets are essential in improving PSS among students, especially in science learning. Previous studies have shown that problem-based worksheets can improve problem-solving skills (Hendriani & Gusteti, 2021; Fitriyani et al., 2019; Desi et al., 2019). The application of e-worksheets with a PBL model can improve PSS (Fitriana & Savitri, 2024).

Virtual labs have become an innovative solution in science education, especially in improving students' PSS. Research shows that virtual laboratories can provide an interactive learning experience that can improve problem-solving skills (Supahar & Widodo, 2021). Virtual labs significantly improve problem-solving skills compared to those who only follow traditional learning (El Kharki et al., 2021). Virtual labs allow students to collaborate in groups, which improves their ability to work together and share ideas in solving problems (Aljuhani et al., 2018). One is using PhET, which is suitable for supporting problem-solving skills (Meisaroh et al., 2020). Therefore, integrating virtual laboratories in science learning

can be an effective strategy to develop students' abilities in analyzing solutions to problems.

With the various explanations of the information above, the researcher developed a STEM-PBL worksheet integrated with a virtual laboratory. The research on the STEM-PBL Student Worksheet integrated with virtual Practice aims to create learning resources that can facilitate the learning process for students. This worksheet is designed to integrate the STEM and PBL approaches and the virtual laboratory. Through this worksheet, students can be actively involved in learning, improve critical and creative thinking skills, and develop problem-solving skills. This study's findings can guide teachers in creating innovative learning resources that meet student needs.

Methods

This research employs the research and development (R&D) methodology, specifically utilizing the 4D development model originated by Thiagarajan, which consists of four stages: define, design, develop, and disseminate. The development of the STEM-PBL worksheet integrated with the virtual laboratory. The initial phase involves conducting three types of analyses: needs analysis, curriculum analysis, and analysis of student characteristics to determine the objectives and scope of worksheet development. The second stage is design, where the worksheet's initial draft is prepared and integrated with the virtual laboratory and problem-solving skills assessment instruments. In the third stage, development, expert validation, revision, and limited trials are carried out to obtain a STEM-PBL worksheet product integrated with the virtual laboratory that is suitable for use. The final worksheet product is implemented in one of the classes to evaluate its effectiveness in improving students' problem-solving skills. (3) The dissemination stage in the 4D development model is the last stage, which aims to disseminate the learning products that have been developed. The 4D stages adopted from Buhera et al. (2024) as illustrated in Figure 1.

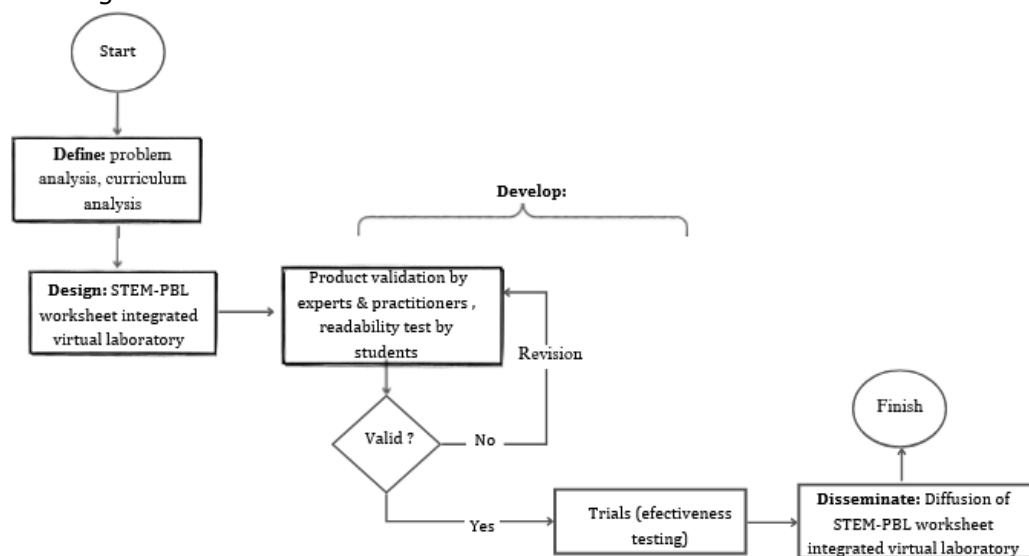


Figure 1. 4D model stages

The STEM-PBL worksheet was validated by four experts: a media expert, a content expert, and two practitioners. The validation used the Guttman scale, where positive responses ("yes") were scored as 1, and negative responses ("no") were scored as 0. The results were then analyzed using Aiken's V formula, as shown in equation 1.

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

Information: V = rater agreement index, s = represents the score given by each rater after subtracting the lowest possible score in the category ($s = r - I_o$), r = score chosen by each rater within their category, I_o = lowest available score in the scoring category, n = total number of raters involved, c = indicates how many different categories were selected by the raters. The results of the validation are divided into 3 categories, as in Table 1 (Retnawati, 2016).

Table 1. Aikens' V category

No.	Score of Aikens'V	Category of Validity
1	$V < 0.4$	Low validity
2	$0.4 \leq V \leq 0.8$	Medium validity
3	$V > 0.8$	High validity

The worksheet's practicality is examined using a Likert scale of 1 to 4, with 5 aspects of readability. Each aspect of the readability questionnaire consists of 4 to 6 statements. The readability test uses 10 students selected by purposive sampling based on academic ability levels. Then, it is analyzed using equation 2.

$$P = \frac{\sum X}{\sum X_i} \quad (2)$$

Description: P = percentage of practicality, $\sum X$ = score obtained, $\sum X_i$ = maximum score. Categorization of the practicality of the developed worksheets, as in Table 2.

Table 2. Categories of practical value

No.	Practicality Value (%)	Category
1	$85 < P \leq 100$	Very Practical
2	$70 < P \leq 85$	Practical
3	$55 < P \leq 70$	Enough Practical
4	$40 < P \leq 55$	Less practical
5	$0 < P \leq 40$	Not Practical

The material used in the worksheet is density. Table 3 shows the indicators on the problem-solving skills instrument, both pretest and post-test.

Table 3. Problem-solving skills indicators

No.	PSS Indicators	Question Indicator
1	Identification Problem	Analyze condition float an object connect density objects and density fluid; Identifying the problem main in the determination of mass type object using the method of water displacement;
2	Solution Planning	Determine step the right start in election material to design a boat miniature based on draft floating and sinking; Determine the suitable method for comparing the density of two types of liquid that is not mixed;
3	Solution Implementation	Count mass burden maximum that can be transported boat miniature based on principle mass type; Identifying the type of material composition cube based on calculation density table types and data density of various materials;

4	Solution Evaluation	Analyze step breakdown of the right problem when test results in boat miniature No per calculation theoretical; Determine the method of proper verification to confirm the type of object based on the characteristic density of its type; Analyze true conclusion about the mass type of rock based on known mass and volume data;
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The study employed a pre-experimental research approach utilizing a one-group pretest-posttest design to implement the STEM-PBL worksheet. The research was conducted with 36 seventh-grade students from class VII-C at SMPN 11 Yogyakarta. The kind of research is shown in Table 4.

Table 4. One group pretest-posttest design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2
Description:	O_1 = A pretest is given before the learning activity O_2 = Posttest given after learning activities X = learning using integrated STEM-PBL worksheets virtual laboratory		

Using N-gain values, we can determine the effectiveness of STEM-PBL worksheets in improving problem-solving skills. The N-gain formula is shown in Equation 3.

$$N\text{-gain} = \frac{S_{\text{posttest}} - S_{\text{pretest}}}{S_{\text{maximum}} - S_{\text{pretest}}} \quad (3)$$

Table 5 shows the classification of N-gain scores (Saputri & Tirtoni, 2022).

Table 5. N-gain value category

No.	Value	Category
1	$N\text{-gain} > 0.7$	High
2	$0.3 < N\text{-gain} \leq 0.7$	Medium
3	$N\text{-gain} \leq 0.3$	Low

Results and Discussion

In the first stage in the development of the STEM-PBL worksheet integrated with the virtual laboratory, namely the define stage, a needs analysis and identification of problems that occur in learning are carried out. Researchers conduct observations and interviews with teachers in this stage to determine current learning conditions and needs. Curriculum analysis is also carried out to align the contents of the worksheet with learning achievements and objectives. In addition, researchers identify the characteristics of students who will be the target users of the worksheet. The results of this defined stage are the basis for designing STEM-PBL worksheets integrated with a virtual laboratory based on learning needs and problems.

The next stage is design. At this stage, the initial design of the worksheet integrated with the virtual laboratory is prepared. The steps taken include: (1) determining learning objectives, competency achievement indicators, and problem-solving skills to be developed; (2) designing worksheet content and activities based on STEM-PBL; (3) developing virtual laboratory guidelines that are by the topic and learning objectives; (4) integrating virtual laboratory into a worksheet as a means to enrich students' learning experiences; and (5) preparing assessment instruments to measure problem-solving skills. The initial design of the STEM-PBL worksheet integrated with the virtual laboratory will then be continued to the development stage to produce a final product ready to be implemented. The developed worksheet's design can be seen in Figures 1, 2, and 3.

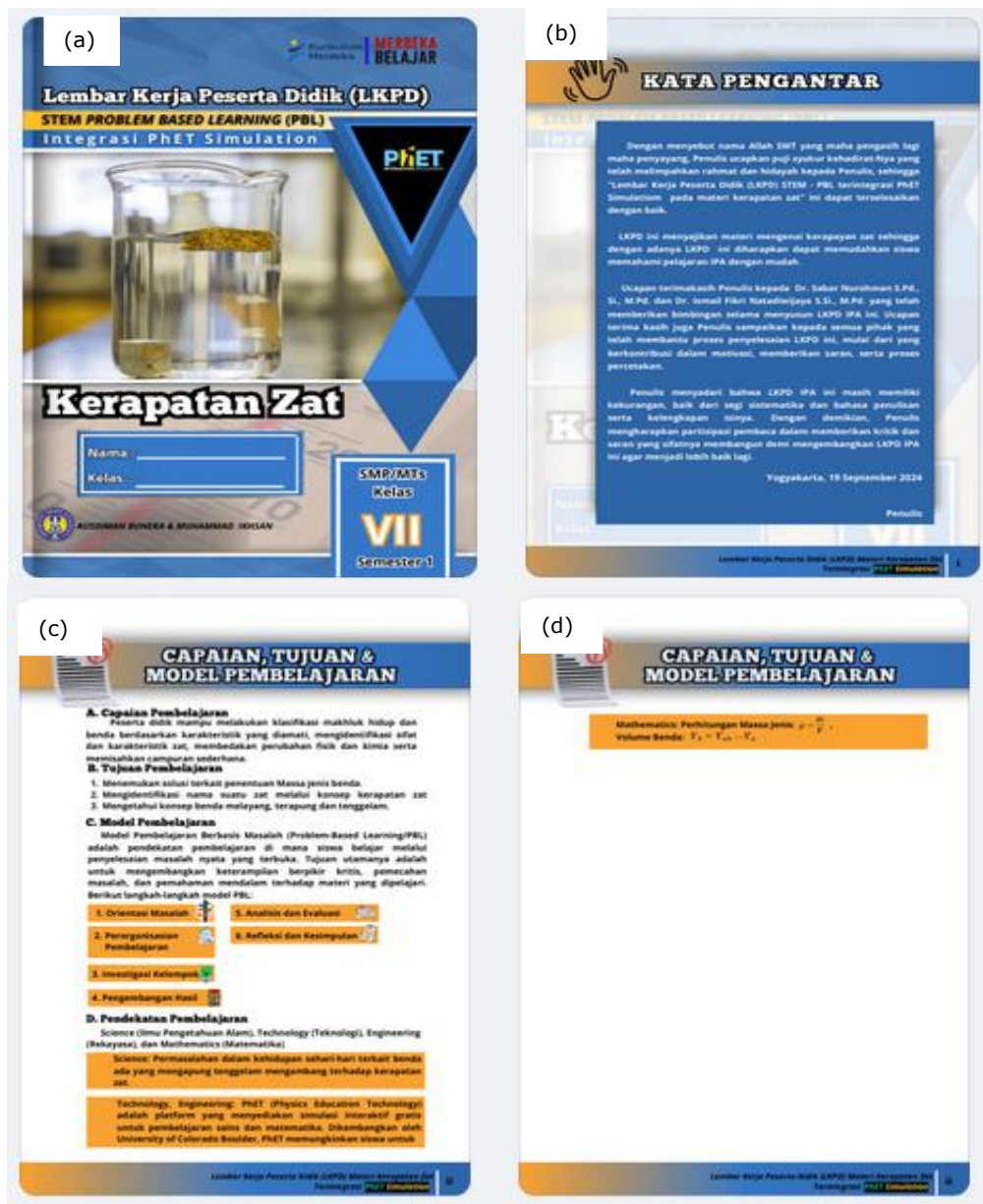


Figure 1. Initial view of the STEM-PBL worksheet: (a) cover, (b) introduction, (c) and (d) learning achievements, goal, and learning Model



Figure 3. Additional Information: (a),(b),(c) reading Materials and (d) author information

After the worksheet is designed, the next stage is development, namely validating the product developed by experts and practitioners and testing its readability to students. The validation results of the STEM-PBL worksheet, as determined by the validators, are detailed in Table 5.

Table 5. Results of the validation of STEM-PBL worksheet by validators

No.	Aspect	Validators				Aiken's Index	Category
		1	2	3	4		
1	Eligibility content/material	4	4	4	3	0.92	High
2	Eligibility presentation	3	4	4	4	0.92	High
3	Language Eligibility	4	4	4	4	1	High
4	Compliance with the PBL model	4	4	4	4	1	High
5	Compliance with the STEM approach	4	3	3	4	0.83	High
6	Virtual laboratory feasibility	4	4	4	4	1	High

Table 5 shows the result of the validator's validation of the STEM-PBL worksheet. All aspects assessed received the **"High" category** with a high Aiken's Index value. Aspects of **the feasibility of content/material** and **the feasibility of presentation** have an index value of 0.92, indicating excellent quality in both aspects. The aspects of **language feasibility, suitability with the PBL model, and virtual laboratory feasibility** obtained the highest value with an index of 1, indicating that the worksheet meets the ideal criteria in all three aspects. Meanwhile, the aspect of **suitability with the STEM approach** has an index value of 0.83, which is also included in the **"High" category**, although slightly lower than other aspects. Overall, the STEM-PBL worksheet is considered valid and meets the criteria for excellent quality. Hence, it can be effectively employed in learning environments. The practicality assessment conducted by students is documented in Table 6.

Table 6. Results of the practicality test of the STEM-PBL worksheet by students

No.	Aspect	Score obtained	Result of Practicality (%)	Category
1	Convenience instructions and usage	38	95	Very Practical
2	Clarity instructions and guides	47	94	Very Practical
3	Simulation integration Effective PhET	56	93	Very Practical
4	Support learning independent	55	92	Very Practical
5	Compliance with the needs of a student	45	90	Very Practical

Table 6 illustrates the outcomes of the practicality assessment of the STEM-PBL worksheet by students; all aspects assessed received the category **"very practical"** with a high practicality value. The **ease of instructions and use** received the highest value of 95%, followed by **clarity of instructions and guidance** with 94%, and **effective integration of PhET simulations** with 93%. Furthermore, **supporting independent learning** obtained a practicality score of 92%, and **the suitability to student needs** obtained a score of 90%. Overall, the STEM-PBL worksheet is considered very practical and effective to use in learning because it meets student needs with clear instructions, supports independent learning, and optimizes PhET simulations. Seeing the effectiveness of the STEM-PBL worksheet through the N-gain value. The N-gain values for each problem-solving skills indicator are presented in Table 7.

Table 7. N-gain value for each PSS indicator

No.	Problem-solving skills indicators	Pretest	Posttest	N-gain	Category
1	Identification Problem	37	72	0.56	Medium
2	Solution Planning	19	61	0.52	Medium
3	Solution Implementation	33	78	0.70	Medium
4	Solution Evaluation	59	69	0.25	Low
Average Problem-solving skills score		37	70	0.51	Medium

Based on the data analysis above shows that students' problem-solving skills increased in each indicator after being given treatment. The solution implementation indicator demonstrated the most significant improvement, achieving an N-gain of 0.70, within the medium effectiveness range. Subsequently, the problem identification indicator showed a moderate increase with an N-gain of 0.56, also categorized as medium. The solution planning indicator followed closely, registering an N-gain of 0.52, similarly classified in the medium category. Meanwhile, the lowest increase was in the solution evaluation indicator, with an N-gain of 0.25 (low category). Overall, students' average problem-solving skills score increased from 37 in the pretest to 70 in the posttest with an

N-gain of 0.51, included in the medium category. This research shows that the STEM-PBL worksheet integrated with the virtual laboratory effectively improves students' problem-solving skills.

Based on the Shapiro-Wilk normality test conducted on the pre-test and post-test data, it was found that the data was not normally distributed. This conclusion is supported by a significance value (p) less than 0.05 ($p < 0.05$), leading to the rejection of H_0 , indicating that the data does not follow a normal distribution. Since the normality assumption is not satisfied, the analysis proceeds with a non-parametric test, specifically the Wilcoxon signed rank test, to assess the difference between the pre-test and post-test, as presented in Table 8.

Table 8. Wilcoxon Signed rank test

	Rank	N	Mean of Rank	Sum of Ranks	Z	Asymp.Sig. (2-tailed)
Pretest-Posttest PSS	Negative	0	.00	.00	-5.237	.000
	Positive	36	18.50	666.00		

Based on the Wilcoxon signed rank test results, the Z value was -5.237 with a significance value (Asymp. Sig 2-tailed) of 0.000, less than 0.05. This indicates a significant difference in students' problem-solving skills before and after the treatment.

The dissemination stage in the 4D development model is the final stage, which aims to disseminate the developed learning products to schools that need them. After going through product validation, readability, and effectiveness tests, the next step is to create a scientific paper related to the developed product. This research shows that the developed worksheet is suitable, practical, and effective in enhancing students' problem-solving skills.

Several prior studies have demonstrated that STEM-PBL-based learning can improve students' problem-solving skills (Parno et al., 2019; Hayuana et al., 2023; Irawan et al., 2024; Parno et al., 2021). The use of virtual laboratories with PhET can improve students' problem-solving skills (Mashami et al., 2023; Wang, 2022; Sari et al., 2018). The use of problem-based learning worksheets can enhance problem-solving abilities (Sinurat et al., 2022; Melawati et al., 2022; Ratih & Rohaeti, 2024; Yanto, 2019). Implementation of problem-based learning models can enhance problem-solving abilities (Kusumawardani & Aminatun, 2024; Knöpfel et al., 2024; Ekasari et al., 2023).

In addition, by integrating virtual laboratories, one of which is PhET, and improving PSS. It can also improve science process skills (Buhera et al., 2024; Ngadinem, 2019; Wata et al., 2022). Effectively improving critical thinking (Viratama & Maskhuliah, 2022; Anjani et al., 2023). The use of PhET in science learning can enhance student learning outcomes (Arifudin, 2021; Prasetya et al., 2022).

Conclusion

Based on the research findings, the STEM-PBL worksheet integrated with the developed virtual laboratory meets the validity, practicality, and effectiveness criteria. The validation results indicate that all aspects fall into the "High" category, with Aiken's Index values ranging from 0.83 to 1.00. Specifically, language feasibility, PBL alignment, and virtual laboratory feasibility achieve perfect scores. In terms of practicality, students rated the worksheet as very Practical, with scores ranging from 90% to 95% across all aspects, particularly in ease of instruction and usability. The effectiveness of the worksheet is demonstrated by the improvement in students' problem-solving skills, with an N-gain score of 0.51 (medium category), further supported by Wilcoxon test results, which reveal a significant difference between pretest and posttest scores ($\text{sig. } 0.000 < 0.05$). Therefore,

the STEM-PBL worksheet integrated with the virtual laboratory is feasible and effective as a teaching material for enhancing students' problem-solving skills.

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