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Development of stem-integrated PjBL model to improve students' scientific literacy competencies

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ABSTRACT

This study aims to develop STEM-integrated Project-based Learning (PjBL) model that meets the criteria of validity, practicality, effectiveness, and consistency in enhancing the scientific literacy competencies of junior high school students. The present research follows the principles of development research, specifically the Research and Development (R&D) 4-D model, which encompasses four stages of activity: define, design, develop, and disseminate. A combination of limited and extensive experiments was conducted to assess the impact of the STEM-integrated PjBL model. The study employed the static one-group pretest-posttest design as the framework for implementing these experiments. Subsequently, the research data underwent descriptive qualitative and inferential analyses, utilizing the two-mean difference test via t-test. The data analysis concludes that the developed STEM-integrated PjBL model learning tools satisfy various criteria. Firstly, the STEM-Integrated PkBL Model is considered valid if the average score exceeds 2.50 and a reliability coefficient value greater than 75%. Secondly, the learning device components demonstrate practicality, indicating their successful application in an educational setting. Lastly, the effectiveness of the tools is demonstrated by a moderate average value of n-gain (0.70), indicating a positive improvement in scientific literacy, further supported by the t-test results (sig. 0.00 < 0.005) that indicate significant progress. Thus, it can be concluded that the STEM-integrated PjBL model learning is suitable for teaching scientific literacy and enhancing the scientific literacy competencies of junior high school students.
Keywords: STEM-integrated PjBL model, learning tools, science literacy, junior high school student.

1. INTRODUCTION

Technology significantly impacts education, as it has become integral to life. The progress of technology goes hand in hand with the development of education. Learning technology refers to the theory and practice of designing, developing, utilizing, managing, and evaluating processes and resources for learning (Hanum & Suprayekti, 2019). Nelson stated that someone who is scientifically literate possesses two abilities: (1) the ability to understand the relationship between the universe, science, and technology, and (2) the ability to apply scientific knowledge and skills individually to make decisions and analyze social issues (socio-scientific issues). These two abilities are the primary goals of 21st-century science education (Takda et al., 2019).

There are two important reasons for the importance of science literacy: (1) the world today is highly dependent on science and technology, and (2) every citizen needs to understand the potential misuse of science (Wendt, 2013). Bybee (2013) proposed that science literacy should be "science for all," aiming to achieve societal aspirations and promote individual development in the context of science and technology. Internationally, it has been agreed that the primary goal of developing science literacy is to enable learners to understand the social implications of scientific and technological questions and actively participate in the associated debates (Rahayuni, 2016).

Scientific literacy is a necessity for everyone. It is highly important for individuals because the progress or decline of a nation is partly determined by the quality of its human resources, who possess literacy in science and technology (Fensham, 2008). Research on students' scientific literacy skills at an international scale is conducted by the Organization for Economic Co-operation and Development (OECD) through the Programme for International Student Assessment (PISA).

Based on the assessment results of the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS), it is evident that the scientific literacy of Indonesian students is still low and tends to decline over the years. Looking at the rankings of scientific literacy achievement in 2000 and 2003, the score was 38. In 2009, the average score was 60, with a mean score of 388. 2012, the average score was 64, with a mean score of 382. In 2015, the score was 403. In 2018, the average score was 71, with a mean score of 396. The low scientific literacy of students can be seen as an indicator that science education in Indonesia still requires improvement.

Based on preliminary studies conducted in junior high schools in Bombana Regency, students' literacy understanding is categorized as very low. This is evidenced by the results of the initial scientific literacy knowledge assessment, consisting of four components. According to Fivest et al. (2014): 1) the role of science with a percentage of 41.7%, 2) scientific thinking and working with a percentage of 42.4%, 3) science and society with a percentage of 30.1%, and 4) mathematics and science with a percentage of 44.6%. The percentages obtained for all four components fall within the deficient category. The factors suspected to contribute to the low scientific literacy include the education system applied, the selection of models, approaches, and learning strategies, the choice of learning resources, students' learning styles, and the facilities and infrastructure available for learning (Khoiriyah & Wahyudi, 2018). Therefore, this study uses a learning model integrated with the STEM approach to support students' scientific literacy skills by implementing the Project-based Learning (PjBL) model integrated with STEM.

One of the learning models that can be used to enhance students' scientific literacy competence is the integrated STEM Project-based Learning (PjBL) model. The integrated STEM PjBL model is a learning context designed by teachers to engage students in learning activities actively (Siew et al., 2015). It serves the purpose of enhancing scientific literacy skills. This is supported by previous research findings that implementing integrated STEM PjBL can improve scientific literacy, particularly when considering gender differences among students (Afriana et al., 2016). The integrated STEM PjBL model impacts Scientific Literacy, Creativity, and students' learning outcomes (Lutfi et al., 2017).

Integrating STEM Project-based Learning (PjBL) in instruction aims to positively impact students' scientific literacy, creativity, and learning outcomes. PjBL integrated with STEM is suitable for teaching science subjects in junior high school, as it is closely related to technology, engineering, and mathematics. Based on the analysis of content standards, one potential science topic that can be taught using integrated STEM-PjBL is Material Classification. In the Ministry of Education and Culture Regulation No. 22 of 2016, which outlines the content standards of the 2013 curriculum, the learning outcomes include Competency Basic (KD) 3.3: Explaining the concept of mixtures and pure substances (elements and compounds), their physical and chemical properties, and the everyday physical and chemical changes. Competency Basic (KD) 4.3: Presenting investigation results or works related to the properties of solutions, physical and chemical changes, or separation of mixtures.

Some relevant studies include a study by Riyanti (2020) researched "Development of STEM-Integrated Project-Based Learning (PjBL) E-Learning Materials to Enhance Students' Creative Thinking Skills." This research concluded that the developed instructional materials met the validity criteria, including the syllabus, Lesson Implementation Plan, Student Worksheets, and assessment instruments. The developed instructional materials received positive responses from teachers due to their user-friendly nature and support for distance learning, which is currently needed. Another study conducted by Fatimah (2017) demonstrated that the implementation of the STEM approach in PjBL-based instruction can develop 21st-century skills such as critical and problem-solving skills, creativity and innovation, communication and collaboration, information literacy, media literacy, technology literacy, flexibility, and adaptability. According to Reza (2017), the STEM approach using project-based learning can develop students' soft skills, including teamwork, empathy, communication, critical thinking, environmental awareness, hard work, adaptability, responsibility, creative thinking, scientific literacy, leadership, curiosity, and honesty.

Furthermore, the aim of this study is to develop a valid, practical, and effective PjBL-integrated STEM instructional model for the topic of Material Classification in 7th-grade junior high school. The goal is to enhance students' scientific literacy competence. Based on the aforementioned explanation, the author researched "Development of STEM-Integrated PjBL Model to Improve Scientific Literacy Understanding."

2. METHODS

a. Research Model

This research is conducted to develop instructional materials. The main objective of this research method is not to generate new theories or test existing theories but to produce a new product or enhance an existing product. The development model used in this research refers to the 4-D development model, which consists of four stages: Define, Design, Develop, and Disseminate. The 4-D development model was introduced by Thaigrajan et al. in 1976.

b. Research Procedure

The main steps in conducting this development research refer to the 4-D Model, which consists of four stages: Define, Design (resulting in draft 1), Develop (resulting in draft 2, which underwent limited trials), and Disseminate (conducting trials on a larger scale). The extensive trials were conducted in two classes at SMP Negeri 05 Poleang Timur, Class VII.1 and Class VII.3. The 4-D development model was introduced by Thiagarajan et al. (1976).

c. Research Location and Subjects.

This research was conducted at SMP Negeri 05 Poleang Timur in the odd semester of the academic year 2021/2022. The subjects in this study were divided into several stages.

- The subject of validation for the integrated STEM PjBL learning model is three experts: two education and subject matter experts and one expert practitioner in science education. The education experts are Dr. Jahidin, S.Pd., M.Si, and Nourmo Yulita, M.Pd. As for the practitioner expert, it is Hidayati Fauziah, S.Pd., M.Sc.
- The subject of the Limited Trial is 15 students from Grade VII.2
- The subject of the Extensive Trial is 30 students from Grade VII.1 and Grade VII.3.

d. Research Instrument

The instruments used in this research are based on the research and development design; therefore, the data collection techniques include:

- The Validation Instrument for the integrated STEM- PjBL Learning Model is provided as statements with a formulated scale by Arikunto (2010). It includes the options of highly valid, valid, less valid, and not valid, along with comments and suggestions from the experts.
- The Observation and Questionnaire Instruments: Observation involves observing the implementation of the learning process by placing a checkmark (√) in each provided space or column. The questionnaire instrument is in the form of a binary scale, where students only need to mark a checkmark (√) for "Yes" or "No" options regarding each component aspect (module, student worksheets, teacher's teaching methods, learning atmosphere), novelty, understanding, interest, and the teacher's explanations during the learning process.
- The Science Literacy Assessment Instrument: In assessing the science literacy of the students in this research, a science literacy competence test was used. The test was developed based on indicators and presented in 20 multiple-choice questions.

e. Data Analysis Techniques

The data analysis technique in this research is described based on the type of instrument used in each stage of the research and development process.

The data analysis from the learning device's validation is conducted using a qualitative descriptive technique with the average scores provided by the validators and category analysis. The categories assigned to the average scores given by each validator refer to the criteria formulated by (Arikunto, 2010).

Table 1. Criteria for Assessing the Validation of the integrated STEM PjBL Learning Model.

Score Indicators	Category
3,25 < *Score* ≤ 4,0	Highly Valid
2,50 < *Score* ≤ 3,25	Valid

$1,75 < Score \leq 2,50$	Reasonably valid
$1,0 < Score \leq 1,75$	invalid

Reliability analysis is also conducted based on inter-observer agreement obtained from the statistical analysis of the percentage of agreement (R), formulated by (Borich, 1944).

$$R = \left[1 - \frac{A - B}{A + B}\right] \times 100\%$$

With R as the reliability coefficient, A as the frequency of observed behavioral aspects that provide the highest score, and B as the frequency of observed behavioral aspects that provide the lowest score. According to Borich (1944), an instrument is categorized as good if it has a reliability coefficient (R) > 75%.

The analysis of students' activities in participating in the integrated STEM PjBL learning model is analyzed quantitatively through descriptive analysis in the form of percentages using the equation.

$$P = \frac{100f}{N} \times 100\%$$

Based on the research results on the implementation of the integrated STEM PjBL learning model, it was analyzed using descriptive-qualitative statistics in the form of mean, percentage, and categories through the normalized gain score (n-gain) test and hypothesis testing.

3. RESULTS AND DISCUSSION

a. Result

- Validation of Learning Device

A PjBL-integrated STEM learning device validated by three validators: syllabus, lesson plans, modules, worksheets, and assessment sheets.

Table 1. Validation Results of the Integrated STEM PjBL Learning Device.

Learning Tools	Average Score	Category
Syllabus	3.9	highly valid
Lesson Plans	3.95	highly valid
Modules	3.8	highly valid
Worksheets	3.7	highly valid
Assessment Sheets	3.9	highly valid

It indicates that the average scores obtained are categorized as highly valid (HV), and the reliability coefficients (R) for the syllabus is 95.9%, lesson plans are 97.8%, teaching materials are 93.3%, worksheets are 91.4%, and assessment sheets is 95.8%, which fall into the reliable category. The reliability coefficient values (R) have met the requirement for inter-observer agreement, which is 75%, indicating reliability (Borich, 1944).

- **Implementation Stage of Integrated STEM PjBL Learning Model.**

The implementation of the integrated STEM PjBL model phase and the implementation of teaching and learning activities during limited and extensive trials showed that the average scores from the observer's observations during the integrated STEM PjBL model learning increased from the first meeting to the fourth meeting, categorized as good (G) and very good (VG). Furthermore, reliability coefficients (R) were obtained for each meeting, which was above 75%, indicating compliance with the 75% inter-observer agreement. Thus, the observation results of teacher activity during the integrated STEM PjBL model implementation showed good and reliable categories (Borich, 1944).

Table 2. The Implementation of PjBL integrated with STEM in the pilot class

No	Steps of Learning	Meeting Number-											
		1			2			3			4		
		$\bar{V}$	%	Not	$\bar{V}$	%	Not	$\bar{V}$	%	Not	$\bar{V}$	%	Not
1	Introduction Activity	3.3	100%	VG	3,5	95%	VG	3.8	96%	VG	3.8	96%	VG
2	Core activity	3.1	98%	G	3.0	97%	G	3.8	98%	VG	3.7	99%	VG
3	Closing activity	3.1	96%	G	3.2	95%	G	3.6	96%	VG	3.5	95%	VG
4	Time allocation	2.0	100%	VG	3.0	100%	G	3.0	100%	G	4.0	100%	VG
5	Class atmosphere	3.2	97%	G	3.2	100%	G	3.7	98%	VG	4.0	100%	VG
	Average	**2.9**	**98%**	**G**	**3.3**	**97%**	**VG**	**3.6**	**98%**	**VG**	**3.9**	**98%**	**VG**

Note: v = Average score from observation; G = Good; VG = Very Good

Table 3. The implementation of PjBL integrated with STEM in the extensive assessment of the 7th-grade class, section 1.

No	Steps of Learning	Meeting Number- 1			2			3			4		
		$\overline{V}$	%	Not	$\overline{V}$	%	Not	$\overline{V}$	%	Not	$\overline{V}$	%	Not
1	Introduction Activity	3.5	95%	VG	3,8	96%	VG	4.0	100%	VG	4.0	100%	VG
2	Core activity	3.5	99%	VG	3.6	100%	VG	3.9	98%	VG	3.8	100%	VG
3	Closing activity	2.8	100%	G	3.2	95%	G	3.8	96%	VG	3.5	95%	VG
4	Time allocation	2.0	100%	G	3.0	100%	G	3.0	100%	B	4.0	100%	VG
5	Class atmosphere	3.7	100%	VG	3.8	98%	VG	3.8	100%	VG	4.0	100%	VG
	Average	**3.3**	**98%**	**VG**	**3.6**	**100%**	**VG**	**3.9**	**98%**	**VG**	**3.66**	**99%**	**VG**

Note: v = Average score from observation; G = Good; VG = Very Good

Table 4. The implementation of PjBL integrated with STEM in the extensive assessment of the 7th-grade class, section 3.

No	Fase	Meeting Number- 1			2			3			4		
		$\overline{V}$	%	Not	$\overline{V}$	%	Not	$\overline{V}$	%	Not	$\overline{V}$	%	Not
1	Introduction Activity	3.7	91%	VG	3,8	96%	VG	4.0	100%	VG	4.0	100%	VG
2	Core activity	3.8	100%	VG	3.8	99%	VG	3.9	98%	VG	3.8	99%	VG
3	Closing activity	3.5	100%	VG	3.8	96%	VG	4.0	100%	VG	3.7	100%	VG
4	Time allocation	3.5	86%	VG	3.0	100%	VG	3.5	86%	VG	4.0	100%	VG
5	Class atmosphere	3.8	100%	VG	3.8	100%	VG	3.8	100%	VG	4.0	100%	VG
	Average	**3.73**	**98%**	**VG**	**3.77**	**98%**	**SB**	**VG**	**99%**	**SB**	**VG**	**99%**	**SB**

Note: v = Average score from observation; G = Good; VG = Very Good

The student's activities during the implementation of teaching and learning activities provide an overview of the implementation of the developed integrated STEM PjBL learning model. Data on student activities were obtained from observations conducted by two observers. The average reliability coefficient (R) from the observations of student activities at each meeting was 96.6%, more significant than the 75% inter-observer agreement (Borich, 1944). This indicates that the observations of student activities in the 7th grade of SMP Negeri 05 Poleang Timur during the implementation of the integrated STEM PjBL learning model meet the criteria of being good and reliable.

- **Description Stage of the Effectiveness of the Integrated STEM PjBL Learning Model.**

With the help of SPSS software, the results of basic analysis testing were obtained (Shapiro-Wilk normality test for pretest-posttest and Levene's test for homogeneity of variances for pretest and posttest) during the limited trial in class VII.2 and the extensive trial in classes VII.1 and VII.3 of the integrated STEM PjBL model, with Sig > 0.005.

Table 5. Results of Normality and Homogeneity Testing for Science Literacy Competence Data in the Limited Trial and Extensive Trial.

Class	Statistical Test	Sig	Conclusion
Normality Test			
VII. 2	*pretest*	0.069	H0 rejected (normal data)
	posttest	0.063	H0 rejected (normal data)
VII. 1	*pretest*	0.103	H0 rejected (normal data)
	posttest	0.134	H0 rejected (normal data)
VII. 3	*pretest*	0.078	H0 rejected (normal data)
	posttest	0.099	H0 rejected (normal data)
Homogeneity Test			
VII. 2	*Pretest posttest*	0.323	H0 rejected (homogeneous data)
VII. 1	*pretest-posttest*	0.501	H0 rejected (homogeneous data)
VII. 3	*pretest-posttest*	0.076	H0 rejected (homogeneous data)

Then, a t-test was conducted on the students' science literacy competence, including a paired t-test for the pretest and posttest and an independent t-test for n-gain data during the extensive trial in classes VII.1 and VII.3.

Table 6. Results of t-test for Students' Science Literacy Competence

Class	Statistical Testing	Nilai Sig	P	Conclusion
VII. 2	paired t-test	0.000	< 0.05	H0 is rejected (There is a change.)
VII. 1	paired t-test	0.000	< 0.05	H0 is rejected (There is a change.)
VII. 3	paired t-test	0.000	< 0.05	H0 is rejected (There is a change.)
VII.1- VII.3	n-gain test	0.706	> 0.05	H0 is accepted (There is no change.)

Based on the results of paired t-tests for students in the limited trial (class VII.2) and extensive trial (students in classes VII.1 and VII.3), each obtained a significance level sig (p) < 0.05. This means that the implementation of the integrated STEM PjBL learning model significantly improves students' science literacy competence with a confidence level of 95%.

b. Discussion

High-quality learning materials are crucial as a support system for implementing the integrated STEM PjBL model in the teaching process. Experts have validated the learning materials developed in this study. Two educational experts and one practitioner expert have validated the learning materials' validity. According to Nieveen (2007), cited in Muzakir (2019), a developed learning design is considered valid if it demonstrates novelty (state-of-the-art), has a strong foundation, and exhibits consistency among its components.

The validity data of the learning materials indicate that the Syllabus, Lesson Plans, Teaching Materials, Student Worksheets, and Assessment Sheets fall under the valid and reliable categories, thus making them suitable for use as learning materials for the integrated STEM PjBL model. Furthermore, the assessment sheets for science literacy competence, assessment of student activities and responses, and assessment of instructional implementation can be utilized as research instruments.

The results of the limited trial on the implementation of the integrated STEM PjBL learning model conducted with the students of class VII.2, using the validated and reliable integrated STEM PjBL learning materials, indicate that the components of the integrated STEM PjBL model can be successfully applied and can be continued in the extensive trial.

Based on the data analysis results of the implementation of the integrated STEM PjBL learning model, both through the limited trial in class VII.2 and the extensive trial in classes VII.1 and VII.3, it is evident that teachers can implement the components of the integrated STEM PjBL learning model effectively.

The learning activities of the integrated STEM PjBL model are structured according to the phases/syntax of the developed integrated STEM PjBL learning model, consisting of six phases: determining essential questions (Science), designing project planning (Technology, Engineering, and Mathematics), scheduling (Engineering), monitoring students and project progress (Engineering and Mathematics), testing outcomes (Science and Engineering), and evaluating the experience (Science).

Based on the analysis of the implementation of learning and student activities after the implementation of the integrated STEM PjBL learning model, which falls under the good category, it is presumed that a positive impact of applying the integrated STEM PjBL learning model in integrated science learning towards improving science literacy competence, both in the limited trial and extensive trial.

The highest achievement of students' science literacy competence is in the competency of explaining scientific phenomena (K1), above 80%, while in the competencies of evaluating and designing scientific inquiries (K2) and interpreting data and scientific evidence (K3), the achievement is still below 80%.

Several recent research studies have shown that integrating an approach into a teaching model substantially impacts the achievement level of students' science literacy (King & Freeman, 2011). Based on the analysis of the average n-gain in integrated STEM PjBL learning, it was found that the science literacy ability in the competence dimension showed a high tendency to explain scientific phenomena. However, in the aspect of evaluating/designing scientific inquiries and the aspect of interpreting data and scientific evidence, the tendency was in the moderate category.

These results indicate that this study's integrated STEM PjBL learning model effectively enhances science literacy among junior high school students and similar levels. These findings are supported by the sensitivity testing of science literacy items, which meet the item sensitivity criteria set by Aliken (1997). An item with sensitivity (S) ≥ 0.30 indicates a sufficient sensitivity to learning effects.

Based on the paired t-test results, a significance level of sig(p) < 0.05 was obtained, indicating that the implementation of the integrated STEM PjBL model has a significant impact on improving students' science literacy competencies in both Class VII.1 and Class VII.3. Furthermore, the analysis of the difference in mean science literacy competency scores using the independent samples t-test between the two classes in SMP Negeri 05 Poleang Timur yielded non-significant values of sig(p) > 0.05, indicating no significant difference in the n-gain of science literacy competencies between students in Class VII.1 and Class VII.3. Therefore, it can be concluded that there is consistent evidence of the significant impact of implementing the integrated STEM PjBL model on improving students' science literacy competencies. Hence, the integrated STEM PjBL learning model can be used to enhance students' science literacy.

4. CONCLUSIONS

Based on the previous findings and discussion it can be concluded that the developed STEM-integrated PjBL model fulfill various criteria. Firstly, the STEM-Integrated PkBL Model is considered valid if the average score exceeds 2.50 and a reliability coefficient value greater than 75%. Secondly, the learning device components demonstrate practicality, indicating their successful application in an educational setting. Lastly, the effectiveness of the tools is demonstrated by a moderate average value of n-gain (0.70), indicating a positive improvement in scientific literacy, further supported by the t-test results (sig. 0.00 < 0.005) that indicate significant progress. It indicates that the STEM-integrated PjBL model learning is suitable for teaching scientific literacy and enhancing the scientific literacy competencies of junior high school students.

Acknowledgment

The developed instructional materials for the topic of Matter Classification for Grade VII in junior high school include the Syllabus, Lesson Implementation Plan (RPP), Teaching Materials, Student Worksheets (LKPD), and Assessment Sheets (LP). The development results of the integrated STEM PjBL instructional materials have met the criteria of validity and reliability, making them suitable for implementing the integrated STEM PjBL learning model in the teaching process.

The integrated STEM PjBL learning model at the implementation stage in the integrated science learning process is considered practical. The level of implementation of the integrated STEM PjBL model and the student's participation in the learning process are categorized as good, with a reliability coefficient (R) of > 75%.

In its implementation, the integrated STEM PjBL learning model has fulfilled the element of effectiveness as it can impact improving students' scientific literacy competencies. This can be seen from the average n-gain scores in students' scientific literacy competencies, which are categorized as moderate, and there is a significant difference between the pretest and posttest scores.

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