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STEM-Project based Learning in Physics Concept of Measurement to Enhance High School Students' Scientific Literacy

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Abstract

Students' scientific literacy in understanding physics concepts still needs to improve. This study aims to determine scientific literacy using STEM Project-based Learning (PjBL) in learning physics, especially measurement concepts. The study used the Classroom Action Research (CAR) method with the Kemmis and McTaggart model, including planning, acting, observing, and reflecting. The subjects were students in the tenth grade of SMA Negeri 8 Yogyakarta for the 2023/2024 academic year, consisting of 33 students. The data collection techniques and instruments used a written test with three questions describing scientific literacy, observation, and documentation. STEM-PjBL through project activities carried out in two learning cycles. In the first cycle, the teacher implemented a project for making posters regarding measuring instrument specifications, while in the second cycle, there was a project for making miniature measuring instruments. After the first cycle, students' scientific literacy increased to 0.48 with a moderate category. In the second cycle, it increased to 0.68. Using STEM-PjBL is thought to have just a modest improvement. These results underline the potential of STEM-PjBL as a fundamental teaching tool to improve students' scientific literacy as they show how well it fosters a strong awareness of physics ideas. Future studies could examine the effects of STEM-PjBL on more scientific ideas or within varied educational environments.

Keywords: measurement material, physics concept, scientific literacy, STEM-Project based learning

INTRODUCTION

Indonesian education has experienced a significant evolution in facing the demands of globalization and rapid change. The evolution also affected changes to the curriculum that is now known as the Merdeka Curriculum. The Merdeka Curriculum faces various challenges in its implementation (Ndari et al., 2023; Setyaningsih et al., 2023). The learning model used by many teachers is still teacher-based, so the learning process is not fully student-centered. Teachers feel unprepared for curriculum changes, and students tend to follow their friends' choices in determining their educational paths, often due to social pressure. Lack of enthusiasm from teachers for change, especially in adjusting learning tools, is also an obstacle. Nonetheless, schools have established several plans to help the Merdeka Curriculum be implemented, demonstrating their will to change with the times and meet current issues.

The project-based learning (PjBL) method is key to the Merdeka Curriculum. Students must engage actively in overcoming practical challenges (Fahlevi, 2022; Permatasari & Madiun, 2023). When designing a project, teachers should base it on problem-based learning. The development of a problem-based learning module, integrated with blended learning, provides a structured approach to enhance teaching practices (Maulisa et al., 2024). Through the project activities, students will gain theoretical knowledge, practical skills, and critical thinking abilities, so equipping them with enhanced adaptation to global dynamics.

SMA Negeri 8 Yogyakarta is one of the senior high schools in Yogyakarta. It began implementing the Merdeka Curriculum in the 2023/2024 academic year. The new curriculum encourages the implementation of the project to strengthen the Pancasila student profile. Project activities have also begun to be implemented in each subject, one of which is Physics. However, implementing the Merdeka Curriculum requires appropriate strategies so that students gain an in-depth understanding.

Originally used to describe objectives in scientific education, the phrase "scientific literacy," first surfaced in the 1950s, It underlines the need of advancing scientific knowledge in a democratic society (Choi et al., 2011). By the 1990s, particularly with the release of instructional reform documents in the United States and elsewhere, it became evident that the primary objective of scientific education was The promotion of informed participation in various aspects of life relies on an emphasis on scientific literacy.

Indonesian student's performance in scientific literacy remains concerning. The Program for International Student Assessment (PISA) survey from 2000 to 2018 indicated that the average score was 396, significantly below the OECD average of 489 (Schleicher, 2019). In Yogyakarta City, a region of relatively high educational quality, students scored 434, still 55 points below the OECD benchmark in 2018. Initial findings from a pre-cycle of classroom action research at SMA Negeri 8 Yogyakarta revealed that tenth-grade students had an average scientific literacy score of only 65.60 out of 100.

STEM education offers an alternative method for developing 21st-century skills (Ilma et al., 2023). It was originally called Science, Mathematics, Engineering, and Technology (SMET) and was a STEM initiative initiated by the National Science Foundation (NSF) which stands for science, technology, engineering, and mathematics in 1990 (Sanders, 2009). The aim of integrating STEM education into the educational setting is to provide students with the abilities required to succeed, excel in their chosen professions, and address the challenges and possibilities that will arise in their future careers (Ejiwale et al., 2013; Widya et al., 2019). Conssequently, numerous nations are striving to enhance the educational standards in specific areas by emphasizing STEM (Yildirim, 2016).

The STEM approach can be a strong foundation for implementing project activities in Physics learning (Kelley & Knowles, 2016). STEM integrates concepts from various scientific disciplines, allowing students to connect theory with practical applications in relevant project contexts (Baharin et al., 2018). Students can be involved in projects that involve understanding physics concepts (Utami et al., 2017). PjBL learning has an impact on student engagement (Johnson & Delawsky, 2013), problem-solving skills (Chiang & Lee, 2016), and academic achievement (Chen & Yang, 2019). Projects also allow for concrete observation results by prioritizing real experience as the basis for learning.

One learning model that can be integrated with this approach is Project-based Learning (PjBL) where students are involved in real projects that require the application of STEM concepts. PjBL is a successful educational strategy that emphasizes the development of problem-solving skills, creative thinking, and student collaboration with their peers to generate and use new knowledge (Indrawan et al., 2019). This refers to an inquiry-based learning method in which students engage in knowledge construction by having them develop real-world products and complete meaningful and meaningful projects (Brundiers & Wiek, 2013). Krajcik & Shin (2014) also explained six characteristics of PjBL, including driving questions, participation in educational activities, focus on learning objectives, use of scaffolding technology, collaboration between students, and creation of real artifacts. This learning model allows students to learn through projects that are relevant to everyday life. By combining a STEM approach in PjBL, students can engage in a holistic learning experience, where students not only understand scientific concepts but also develop critical, collaborative, creative thinking skills, cognitive learning outcomes, problem-solving, cooperative learning, and independent learning abilities (Beckett & Slater, 2018; Sinurat etal., 2022). This study aims to analyze scientific literacy using STEM-Project based Learning (PjBL) in learning Physics, especially in Measurement concepts. The research question is how does the implementation of STEM-PjBL affect the scientific literacy of tenth-grade students in the physics concept of measurement.

METHOD

The study used classroom action research (CAR). CAR entails the utilization of qualitative, interpretive approaches to investigation and data gathering by educators, often in collaboration with academic partners or colleagues. The primary goal is for teachers to assess and determine how to enhance the instructional methods they employ (Kemmis et al., 2014). CAR procedure includes planning, acting, observing and reflecting.

Planning

The planning stage includes conducting a needs assessment to identify challenges faced by students, setting clear and achievable goals for the research, designing interventions using STEM-PjBL to be implemented in the classroom, and working with colleagues to develop a comprehensive action plan, including research questions, methodology, and data collection techniques.

Acting

In the implementation phase, key activities include implementing the designed teaching strategies, engaging students in learning activities, and documenting the process through lesson plans, teaching notes, or recordings to capture the implementation of the intervention in real time.

Observing

This stage involves assessing student scientific literacy during and after the intervention. It uses qualitative methods like interviews, focus groups, or surveys for feedback and quantitative data like test scores or attendance to evaluate the impact on scientific literacy.

Reflecting

The reflection stage involves evaluating the strategy's effectiveness using data, discussing findings with colleagues, identifying strengths and weaknesses, considering improvements, and documenting the process for future action research and professional development.

The study was carried out in the odd semester of the 2023/2024 academic year. The subjects of this study are students in XE grade of SMA Negeri 8 Yogyakarta consisting of 33 students. The object is to enhance students' scientific literacy through the implementation of STEM-PjBL. The data collection techniques were carried out using written test instruments, observation, and documentation. The written test consists of three questions describing scientific literacy related to the measurement material according to scientific literacy competency, namely explaining scientific phenomena, evaluating and designing scientific investigations, and interpreting data and evidence scientifically. The written test has been validated by two experts. Validation was conducted to assess the relevance of the questions to instructional goals, the quality of the material, and the language. The validation results show that the instrument is suitable for use. The observation form is used to determine the extent to which the lesson plan has been implemented. Documentation is used to determine the condition of teachers and students, the availability of school and class facilities and infrastructure at SMA Negeri 8 Yogyakarta, and data related to the results of student diagnostic assessments before action is taken.

Quantitative data will be analyzed to see the impact of students' scientific literacy. Researchers find the average value of each pre-test and post-test of each cycle using following equation.

$$\bar{x} = \frac{\sum x}{n} \quad (1)$$

Notes:
$\bar{x}$ = the mean of the student's scientific literacy (maximum scores is 100)
$\sum x$ = the total score from pre-test and post-test
n = the number of the students

The formula used to investigate average of research and scores for improvement of student's scientific literacy.

$$(\%) = \frac{Number\ of\ students\ who\ completed}{Number\ of\ all\ students} x\ 100 \quad (2)$$

The analysis of scientific literacy data has used the N-Gain calculation developed by Hake (1999). It is to determine the enhancement of students' scientific literacy competencies.

$$\langle g \rangle = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \quad (3)$$

Notes :
$\langle g \rangle$ = N-gain
S_{post}= pretest score
S_{pre} = posttest score
S_{max} = maximum score

TABLE 1 explains the scale of N-Gain data values.

TABLE 1. N-Gain

Score N-Gain	Criteria
g > 0.70	High
0.30 ≤ g ≤ 0.70	Medium
g < 0.30	Low

Analysis of test questions and N-Gain enhancement as a determinant of learning success. The percentage of classical completion in the study refers to an enhancement of students' scientific literacy by 85% (Krisdiana & Dwikoranto, 2023; Lestari, 2019) and individual completion reaches a minimum completion criterion of 75.

RESULTS AND DISCUSSION

These findings support the research question. It has succeeded in enhancing scientific literacy, especially in physics concepts of measurement. Students can achieve more than the specified minimum completeness. At each meeting, the researcher gives assignments in the form of projects to be discussed and created by each small group that consists of three or four students.

In the first cycle, the teacher provides stimulus by providing learning videos and readings related to buying and selling phenomenons in traditional markets, which utilize measuring instruments. Stimulus through video displays makes learning more interesting (Mayer et al., 2020), concrete, and accessible to various learning styles, increasing student engagement (Lackmann et al., 2021) and strengthening their understanding of measurement concepts. Students can also confirm their experience by reading. The teacher provides direction in preparing the project schedule and project design that will be made by the students relating to measurement phenomena that are close to life and related to local culture, for example, the process of making Bakpia Pathuk, and helps students to design products for project activities.

Aspects of science in the learning process include measurements, quantities, units, dimensions, and various measuring tools. From the technological aspect, students make posters using Canva software. Students design posters for technical skill aspects through creativity and ideas from student group discussions (see FIGURE 1). Students do a gallery walk to exchange information with other poster groups. Students identify measuring instruments and state measurement errors that may occur.

FIGURE 1. Project Results in First Cycle: Poster about Measuring Tools

In the second cycle, there were improvements in the implementation of STEM-PjBL, especially in projects assigned to students. At the beginning of the lesson, the teacher provides stimulus by showing a learning video related to the traditional marble game. The teacher provides directions in preparing the project schedule and design by measuring the diameter of the marbles. The second learning cycle focuses more on collecting data through practical work using measuring instruments and trying to operate miniature vernier measuring instruments made by students using the materials provided. Students are creative in designing and making vernier calipers from cardboard and other simple materials.

The concept of measurement has a scientific aspect, including the use of vernier calipers and screw micrometers, significant figures, scientific notation, and uncertainty in a single measurement. From the technological aspect, students make miniature vernier caliper measuring instruments using simple tools and materials such as cardboard, scissors, paper containing a vernier caliper scale, and others (see FIGURE 2). Students design miniature vernier calipers as a form of application of engineering aspects. Students identify significant figures and scientific writing in the measurement activities. Students present the results of their work and analysis of experiments carried out in front of the class.

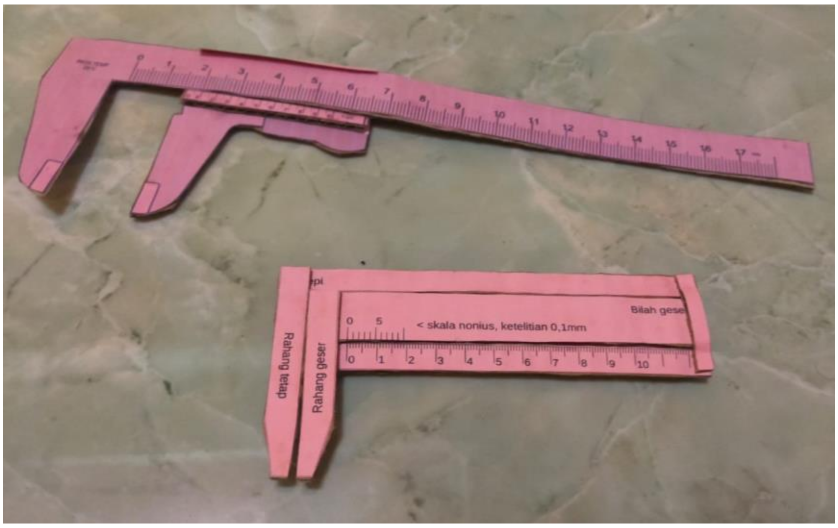

FIGURE 2. Project Results in Second Cycle: Simple Miniature Vernier Calipers

In the poster-making project, students explain physics concepts of measurement such as length, mass, time, and other quantities. This process encourages them to express ideas visually (Gray et al., 2022). Through poster making, students summarize information, choose appropriate visual representations, and explain concepts briefly. It has increased their in-depth understanding, creativity, and communication skills (Wisanti et al., 2024). The miniature project activity also involves measuring tools such as rulers to make calipers. It helps students practice proper measurement skills (Mari et al., 2023). Direct experience in measuring objects and time makes students' understanding of measurement concepts more concrete.

TABLE 2 explains the students' classical science literacy completion from pre-cycle, first cycle, and second cycle.

TABLE 2. Classical Completeness Data on Scientific Literacy of XE Grade Students at SMA Negeri 8 Yogyakarta

No.	Completeness	Scientific Literacy					
		Pre-cycle		First Cycle		Second Cycle	
		Frequency (N)	Percentage (%)	Frequency (N)	Percentage (%)	Frequency (N)	Percentage (%)
1.	Complete	10	69.70	24	73.50	30	90.90
2.	Incomplete	23	30.30	9	26.50	3	9.10
	Average score	65.60		82.15		87.27	
	Maximum	91.00		100.00		100.00	
	Minimum	11.00		32.00		70.00	
	N-Gain			0.48		0.63	

FIGURE 3 displays a bar chart of the average science literacy scores in the pre-cycle, first cycle, and second cycle from the data in TABLE 2.

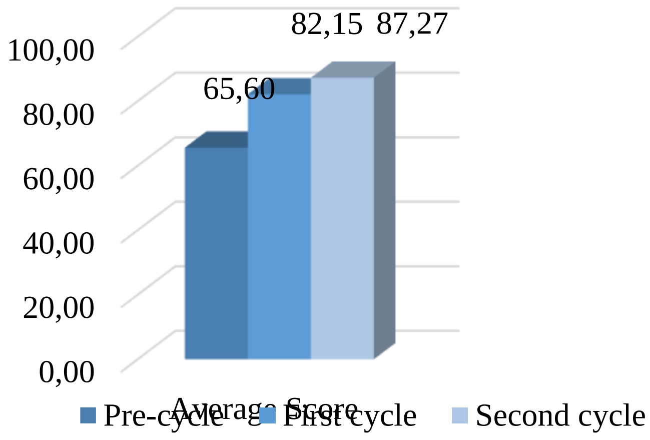

FIGURE 3. Classical Completeness of Students' Scientific Literacy

Baran et al. (2021) explain that student input and opinions become reflections to enhance the learning process. Based on the feedback obtained from students, STEM-PjBL learning makes them more engaged in learning. Project activities can help students understand the concept of Physics, especially measurement. Students feel more confident in applying science concepts after completing the poster and miniature-making projects.

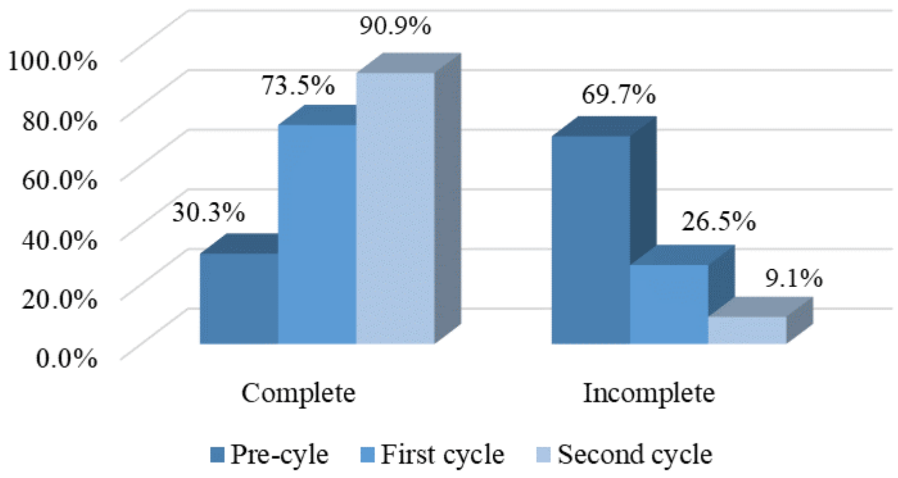

FIGURE 4. Percentage of Students' Scientific Literacy Completeness

Students' scientific literacy in the second cycle has reached minimum completeness (85%). Thirty students completed it with a percentage of 90.9%, while three students did not complete it with a percentage of 9.1% (see FIGURE 4). This percentage of completeness shows that the enhancement in students' scientific literacy is very high. The average scientific literacy score of students in the second cycle reached 87,27. N-Gain students' scientific literacy was 0.48 in the first cycle and 0.63 in the second cycle (see FIGURE 5). Moderate N-Gain indicates that students have successfully understood science concepts and can apply them in relevant contexts. Meanwhile, there are still opportunities for further improvement. Sustainable approaches of additional interventions or support programs for students who may still be struggling can help improve their scientific literacy to a higher level.

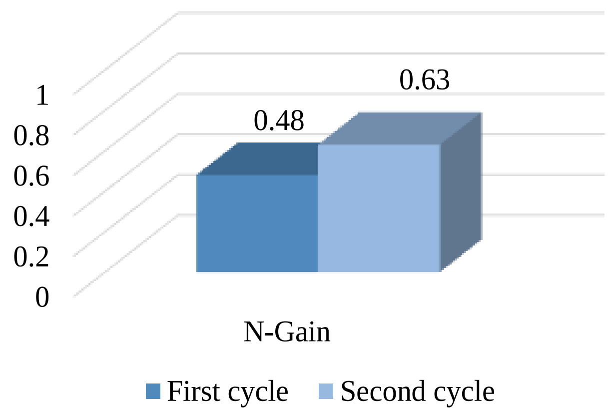

FIGURE 5. N-Gain of Students' Scientific Literacy

This finding is supported by the findings of Winarni et al. (2022) who integrated PjBL-STEM into science literacy in elementary schools, and Anggereini et al. (2023)who identified PjBL and STEM based on socio-science issues to improve students' science literacy. In this study, we found an innovation in the application of STEM-PjBL applied to the Physics measurement concept for high school students which is adjusted to students' abilities in science literacy. In the project activities carried out, students can design works, both posters and miniature measuring instruments, which are assigned by carrying out project creation procedures. Students are also able to connect the content in Physics lessons from the practicum carried out. During the learning process, students actively ask questions to the teacher and their group friends and propose solutions to problems presented in project assignments. Wardani et al., (2021) explained findings related to STEM-PjBL learning which can enhance students' scientific literacy with the highest indicator being the ability to explain scientific phenomena.

The results of the systematic literature review (Simamora, 2024) and meta-analysis (Roslina et al., 2022) studies show that the use of STEM-PJBL has a positive impact on aspects of skills, cognition, and attitudes and can be integrated into media or teaching materials such as STEM applications, modules, worksheets, and teacher awareness. The implementation of the STEM approach can be optimally improved by determining topics, identifying materials, learning models and media, determining learning objectives and variables, and designing progress evaluations (Astra et al., 2023; Ilma et al., 2022). Future research can integrate the STEM approach with other learning models, for example problem-based learning (Kim et al., 2018; Laforce et al., 2017), inquiry learning (Deák et al., 2021; Lai, 2018), and discovery learning (Majid & Majid, 2018; Pramesti et al., 2022).

CONCLUSION

STEM-PjBL can be applied through project activities carried out in two learning cycles. In the first cycle, a project for making posters regarding measuring instrument specifications was implemented, while in the second cycle, a project for making miniature measuring instruments was implemented. The teacher provides stimulus in the form of learning videos, reading texts, or issues related to the surrounding culture which also makes participants more enthusiastic about participating in learning, especially in applying students' scientific literacy. Students' scientific literacy in the first cycle obtained a classical completeness percentage of 73.50% and enhanced in the second cycle where they obtained a percentage of 90.90% with classical completeness set at 85%. Classroom action research through the application of STEM-PjBL can enhance scientific literacy with N-Gain in the first cycle of 0.48, enhancing in the second cycle to 0.63, which is classified as moderate in the measurement material at SMAN 8 Yogyakarta.

STEM-PjBL is a valuable tool for improving science literacy across various educational contexts. These findings are essential for educators, policymakers, and the global community focused on developing scientific literacy. This model improves science literacy and equips students with essential skills needed for their future in an increasingly complex and technology-driven workplace.

The study has several limitations, including the limited sample size reducing the ability to generalize the results to a larger population. In addition, the influence of external factors such as motivation and socio-economic conditions of students can also affect the results. Variations in the implementation of STEM-PJBL by teachers can cause different consistency of results. Future research can explore the impact of STEM-PjBL on other science concepts or in different educational settings.

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