JPPIPA 11(7) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Science Literacy through STEM-Based Project Based Learning Model

Hendrik Pratama[1*], Matsun[2], Yulia Dewi Puspitasari[1], Tri Wahyuni Maduretno[1]

[1] Science Education Study Program, PGRI Mpu Sindok University, Nganjuk, Indonesia.
[2] Physics Education Study Program, PGRI Pontianak University, Pontianak, Indonesia.

Received: May 09, 2025
Revised: June 15, 2025
Accepted: July 25, 2025
Published: July 31, 2025

Corresponding Author:
Hendrik Pratama
pratama@upms.ac.id

DOI: 10.29303/jppipa.v11i7.11306

Abstract: This study explores the project-based STEM (Science, Technology, Engineering and Maths) approach and its effect on science literacy. The research type is quasi-experiment with pretest postest nonequivalent control group design and 84 samples have been selected from 320 population. The project-based STEM approach was applied to the experimental class while the control class used the Problem Based Learning model. The results showed that the project-based STEM approach had a significant effect on science literacy. Measurement of science literacy in the experimental class showed better data than the control class where the assessment focused on aspects of content, process, context, and science attitudes. Students were able to connect science concepts with real-world scenarios. Another impact is that students are trained to work together in groups in developing ideas, solving problems using media projects, and drawing conclusions based on data analysis of investigation results. The novelty of this research is the creation of a new project in understanding nutrient material in the Basic Natural Science course. The resulting project is an IoT-based NPK, pH, temperature, conductivity, and humidity measuring instrument that can not only operate within the scope of the laboratory but can be disseminated to solve real problems.

Keywords: Project based learning; Quasi-experimental design; Science literacy; STEM

Introduction

Science literacy is one of the abilities needed in dealing with technological developments. Literacy helps students understand scientific concepts that can support technological developments such as biotechnology, artificial intelligence, renewable energy, and others (Wen et al., 2020). In its application, science literacy enables students to think critically, analytically and logically. Distinguishing facts from hoaxes to finding facts to prove theories. In addition, science literacy can trigger students to improve their ability to solve complex problems through data analysis and empirical evidence (Savitri et al., 2021). This ability can train individuals in collecting and analysing data, making hypotheses, testing theories, thus allowing them to solve problems with a more contextual approach. On the other hand, technological developments bring new challenges such as climate change issues, environmental sustainability, contextualised educational developments that require modern science and technology-based solutions. Science literacy allows individuals to critically understand issues and contribute to finding innovative solutions (Ke et al., 2021). In addition, in an increasingly competitive world of work, science and technology skills are becoming an essential requirement for many future professions (García-Pérez et al., 2021). Improving science literacy is not only beneficial for individual development, but also for the advancement of society as a whole.

How to Cite:
Pratama, H., Matsun, Puspitasari, Y. D., & Maduretno, T. W. (2025). Science Literacy through STEM-Based Project Based Learning Model. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 320–330. https://doi.org/10.29303/jppipa.v11i7.11306

However, PISA data from 2012 to 2022 shows that the science literacy skills of Indonesian students have fluctuated with a tendency to remain below average (OECD, 2022). Although there was an improvement in the rankings in PISA 2022 compared to 2018, the average score decreased by 12 points, smaller than the global average decrease. Indonesia's science literacy score tended to increase from 382 in 2012 to 403 in 2015, but decreased to 396 in 2018 and continued to decline in 2022. In addition, only a small proportion of Indonesian students reached a high level in science literacy, with the majority still below the basic level (Ramli & Susanti, 2022). This suggests that despite the slight improvement in the rankings, the challenges in improving the quality of science education in Indonesia are still significant and require more comprehensive efforts.

This preliminary study was continued by conducting research on the science literacy skills of students at PGRI Mpu Sindok Nganjuk University, East Java, Indonesia. This test involved 60 students who were taken randomly from 5 study programmes. The assessment of science literacy is based on 4 indicators namely content, process, context, and science attitude which refers to the PISA framework (OECD, 2019). The results are as follows:

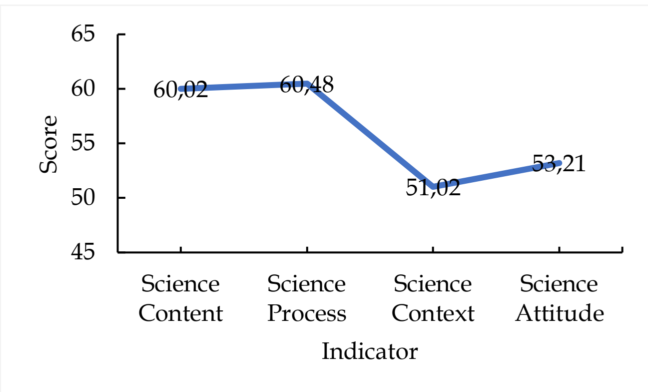

Figure 1. Results of science literacy skills at PGRI Mpu Sindok University Nganjuk East Java Indonesia

Based on Figure 1, the science content aspect scored 60.02 and the science process scored 60.48, both in the low category. In the aspect of science context with a score of 51.02 and science attitude with a score of 53.21 which are both in the very low category. Science content assessment indicators include the ability to connect science concepts (physics, chemistry, and biology) with natural phenomena in everyday life, science process assessment indicators include the ability to understand the concepts of the scientific method, design experiments, collect and analyse data, and interpret them. While science context assessment indicators include the ability to apply scientific knowledge in real situations, understand the relationship between science and technology, society and the environment, and science attitude indicators include attitudes that support the understanding and application of science such as curiosity, openness, responsibility, and critical thinking skills. So, the results show that students' science literacy skills are generally still low.

Based on the urgency above, the focus of the research was conducted by applying innovative learning approaches and relevant to the context of the digital era. One approach that is considered effective is Project-Based Learning (PJBL) integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach. This approach not only teaches science concepts, but also involves students in real projects that integrate technology, engineering, and mathematics that make learning more contextual and meaningful (Samsudın et al., 2020).

PjBL is a student-centred learning model, involving students learning through real projects, conducting in-depth investigations in problem solving (Mutanga, 2024). This model has the characteristic of being able to integrate various disciplines in one activity and produce more concrete products or solutions (Tang, 2023). In its implementation, PjBL emphasises experiential learning with each student actively involved in solving complex problems, conducting investigations, and producing authentic products or solutions. The PjBL model is needed in improving 21st century skills, namely critical thinking, collaboration, creativity, and communication (Amroni et al., 2024). This model has 5 main characteristics, namely challenging questions that trigger curiosity, in-depth investigation in conducting research and analysis, student autonomy that allows students to have control over the learning process, authentic products that can be presented to real audiences, and reflection and revision to evaluate their work (Markula & Aksela, 2022).

There have been many studies related to the effect of PjBL on science literacy. Girgin et al. (2024) stated that PjBL helps students connect science theories with real-world applications, thus improving conceptual understanding. This model trains students in inquiry, data analysis and problem-solving skills which are components of science literacy. Krajcik et al. (2023) found that students in the PjBL group were more skilled in designing experiments and interpreting data. Students were able to answer each problem based on data and products, thus making learning more meaningful.

Meanwhile, STEM is an interdisciplinary approach that connects science, technology, engineering and mathematics in solving problems (Susiloningsih et al., 2025). STEM is the focus of research in science education because of its ability to integrate various disciplines (interdisciplinary) and holistic problem solving (Ortiz-

Revilla et al., 2020). Research related to STEM shows significant results in improving science literacy and student engagement in the learning process (Utami et al., 2020). Students are invited to link their knowledge, create technology to answer problems, design products technically, and analyse them based on valid data (Hafizah, 2021). From this process, STEM is able to improve team collaboration because the products made are done in groups, increase creativity in designing solutions, and of course the use of digital literacy (Owens & Hite, 2022). In the 21st century, the use of technology is undeniably growing rapidly. The STEM approach strongly supports the use of technology where students must seek literacy from various sources in preparing their projects (Falloon et al., 2020).

Several studies related to the benefits of combining PjBL and STEM models include being able to improve science literacy. PjBL with a STEM approach applied in the learning process can significantly improve science literacy, especially critical thinking, problem solving, and understanding of science concepts (Baran et al., 2021). In another study, the application of PjBL and STEM was able to improve understanding of science concepts and connect them to technology, investigative skills, and data analysis (Krajcik et al., 2023). Furthermore, research related to PjBL-STEM is effective in improving students' science literacy in Indonesia, this research is able to integrate science phenomena and apply knowledge in a local context. However, the analysis shows that the three studies have weaknesses, namely not applying technology and digitalisation in revealing scientific phenomena. On average, the concept of technology in the approach used only uses simple project activities. The research did not reveal science projects based on current technology and engineering, advanced technology, and digitalisation. Therefore, the combination of PjBL and STEM is a learning approach based on problem-solving strategies through projects that integrate knowledge concepts with STEM skills. Projects are designed to solve problems relevant to real life based on the knowledge students have (Rohm et al., 2021). While implementing projects, students learn to use the scientific method, apply science as science, technology and engineering in working on products, and mathematics as a basis for analysing research data (Purwaningsih et al., 2020).

Based on this background, the novelty in this study is by applying the PjBL model with a STEM approach or can be abbreviated as PjBL-STEM which uses IoT-based digital technology as a medium for science learning. Researchers apply the PjBL-STEM model through a project to reveal the quality of soil nutrients in the Basic Natural Science course by utilising an IoT-based microcontroller as a learning medium. The design of technology and techniques made in the project is not only applied in revealing science phenomena in the laboratory but also revealing science phenomena in the real environment, such as the quality of soil nutrients on agricultural land. The technology is equipped with sensors that are able to display data in real time so that students can easily analyse and interpret the data. Thus, the formulation of the problem to be researched is as follows: (1) How is the implementation of the PjBL-STEM model that utilises IoT-based microcontrollers in the Basic Natural Science course? (2) How is the effectiveness of the PjBL-STEM model on science literacy?

Method

This study used a type of quasi-experiment with a pretest posttest nonequivalent control group design. This design is used to determine the comparison of students' science literacy skills between the experimental class and the control class (Sholahuddin et al., 2023). The research procedure begins with a pretest for the experimental class using the PjBL-STEM model and the control class using the conventional model, namely Problem Based Learning. After being given treatment, then a posttest was conducted on each group to determine the difference and effectiveness.

The study population was students of Science Education Study Programme and Mathematics Education Study Programme of PGRI Mpu Sindok Nganjuk University, East Java Indonesia. The total population of 320 students and 84 students were taken which were divided into 2 groups. As described in the following table.

Table 1. Characteristics and Distribution of the Sample

Variable		Experimental Class	Control Class
Range Age		20-21	20-21
Gender	Male	5	7
	Female	40	32
Hometown	Nganjuk City (%)	92	90
	Outside Nganjuk City (%)	8	10

The experimental group was taken from the Science Education Study Programme totalling 45 students and divided into 5 males and 40 females. While the group was taken from the Mathematics Study Programme which amounted to 39 students which were divided into 7 men and 32 women. The sampling technique used purposive sampling by selecting based on criteria relevant to the research, the suitability of the selected material, and the linearity of the students' scientific majors (Robinson, 2024). Both samples have the same characteristics, namely being students in semester 3 (three), currently taking Basic Natural Science courses for 2 credits, aged 20-21 years, and on average come from the same city, namely Nganjuk city, East Java Province. All participants in this study have given consent in participating in every activity carried out.

To explore students' science literacy, this research uses test questions. Of course, the science literacy test instrument was designed based on PjBL-STEM to measure science content knowledge, and science applications in everyday life. The test design is arranged in the form of multiple choice consisting of 30 questions. The ice instrument is divided into 2 namely pretest and postest questions. The science literacy test was prepared in such a way that refers to the Programme for International Student Assessment (PISA) which includes 4 aspects namely context, content, competence, and attitude (Cansız & Cansız, 2019). This means that the science literacy test does not only measure students' level of understanding of science knowledge, but understanding of science competence, ability to apply science knowledge and attitudes, and science competence in real situations faced by students.

The research procedure includes planning, implementation, and final stages. The planning stage includes making learning modules, student worksheets, science literacy questions, and literature studies related to science learning. The implementation stage by providing PjBL-STEM learning treatment in the experimental class and conventional models in the control class. Both are applied to the Basic Natural Science course with the subject matter of Natural Science and Technology for Human Life. As the final stage by conducting data analysis, discussion, and drawing conclusions.

The first step of the statistical test is to test the assumptions of normality and homogeneity. The normality test in this study used the Kolmogorov-Smirnov method because the data used were more than 50 respondents (Demir, 2022). The condition is if the significance value is more than 0.05 then the data is normal. For homogeneity if the significance value is more than 0.05 then the data is said to be homogeneous. The results of the normality and homogeneity tests are as follows.

Table 2. Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Score	Experiment	0.078	45	.200*	0.976	45	0.452
	Control	0.094	39	.200*	0.979	39	0.67

a. Lilliefors Significance Correction
*. This is a lower bound of the true significance.

Table 3. Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Score	Based on Mean	0.415	1	82	0.521
	Based on Median	0.389	1	82	0.534
	Based on Median and with adjusted df	0.389	1	79.296	0.534
	Based on trimmed mean	0.406	1	82	0.526

Table 2 above shows that the data is normally distributed based on the Kolmogorov-smirnov test. Evidenced by the significance value of Asiymp.Sig (2-tailed) in both groups of 0.200 which is greater than 0.05 (Muslih et al., 2023). While Table 4 data is also homogeneous. This is evidenced by the Sig. Based on Mean for the variable science literacy test score of both groups of 0.521 is greater than 0.05. So, it can be concluded that the data is normal and homogeneous.

After the average value is tested for normalisation and homogeneity test for both groups, the next step is to conduct statistical tests to determine differences in science literacy. The statistical test used is the t-test of the average of two independent samples with a significant level of α = 5%.

Table 4. Science Literacy Achievement Criteria

Value Range	Category
80-100%	Level 5-6 (High)
70-79%	Level 4 (Medium)
60-69%	Level 3 (Basic)
<60%	Level 1-2 (Low)

Source: OECD (2019). PISA 2018 Assessment and Analytical Framework.

The provisions of the proposed hypothesis if Sig. > 0.05 means H0 is accepted (Brusa & Bahmani-Oskooe, 2020). This means that there is no effect of PjBL-STEM on science literacy. Or Sig. < 0.05 means H0 is rejected. It means that there is an effect of PjBL-STEM on science literacy. Furthermore, the science literacy achievement scores for the experimental and control groups were compared based on indicators, namely content, process, context, and science attitudes. Interpretation based on criteria can be presented in Table 4.

Result and Discussion

Result

The table 5 shows that the experimental class with an average of 84.2667 has a value greater than the control group with an average value of 76.2564. While reviewed from the N-Gain score for the experimental class of 0.32 in the medium category. The control class N-Gain score is 0.15 in the low category.

Table 5. Test Results of Experimental Class Total Science Literacy Score with Control Class

Group	N	Mean	Std. Deviation	Std. Error Mean	N-Gain
Experiment	45	84.2667	5.6705	0.84531	0.32
Control	39	76.2564	4.97741	0.79702	0.15

Table 6. Independent Samples Test Results

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Equal variances assumed	0.415	0.521	6.83	82	0	8.01026	1.17274	5.67729	10.34322
Equal variances not assumed			6.895	81.983	0	8.01026	1.16181	5.69905	10.32147

The result of Sig. (2-tailed) of 0.000 <0.05. So, the results of hypothesis testing show Ho is rejected and Ha is accepted. This result shows that there is an effect of PjBL-STEM on science literacy.

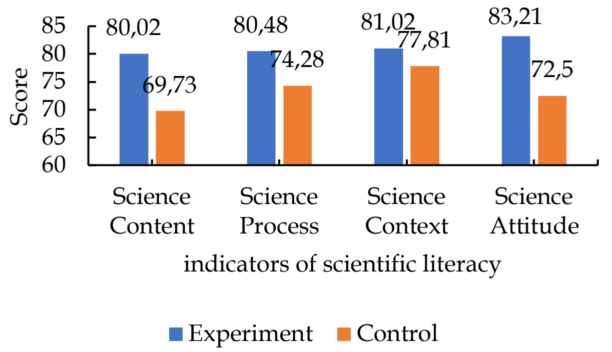

Figure 2. Control class and experimental class science literacy achievement scores

Based on Figure 2, it shows the achievement of science literacy scores in the experimental group is superior to the control group. The percentage of scores refers to Table 5. In all aspects of science content, science process, science context, and science attitude in the experimental class in the high category with scores of 80.02, 80.48, 81.02, and 83.21. While in the control class in the low category (score 69.73) for aspects of science content and others in the medium category with scores 74.28, 77.81, and 72.50.

Discussion

Application of STEM-Based Project Based Learning Model

Project Based Learning (PjBL) with STEM approach or PjBL-STEM are two different learning models philosophically. However, according to the research results of several experts, the collaboration of the two can create a new model that can be a solution in improving the quality of education (Winarni et al., 2022). STEM uses an interdisciplinary approach to learning that integrates with the real world of students (Juškevičienė et al., 2021). This model specifically applies the concepts of science, technology, engineering, and mathematics in building a broad context between school life, daily life, community, and work. Meanwhile, the PjBL model emphasises learning from real-world problems to finding solutions through a series of projects (Santana et al., 2024). This is what makes students interested, able to trigger serious thinking, train thinking skills, and practice collaboration where these abilities are needed in the world of work. PjBL-STEM are both based on problems with authentic real-world contexts. The ability to solve problems can be trained through a series of project-based scientific methods. Directly engaging students with real-world problems to get the right answer is key in building critical and innovative thinking capacity. Furthermore, STEM accommodates ideas into an inseparable whole in the form of projects that are nuanced in science, technology, engineering, and mathematics (Hacker, 2024). These four aspects must work together in an effort to provide solutions.

The research activities began with problem identification. The learning topic taken was determining the quality of soil nutrients in the Basic Natural Science course. The nutrients in question are determining the levels of nitorgen, phosphorus, potassium, pH, moisture, temperature, and conductivity with the practicum sample being soil for shallot fields in Nganjuk Regency, East Java Indonesia. The results of the practicum showed that soil quality had decreased with pH and NPK levels varying from very low to high. In the next step, students accompanied by lecturers designed projects, conducted explorations, and investigations. The result of the discussion was a project in the form of an IoT-based NPK, pH, humidity, conductivity, and temperature measuring device. This project was initiated from the problem of determining the quality of soil nutrients in the Basic Natural Science course and as a form of application of the Science (S) concept in the STEM approach.

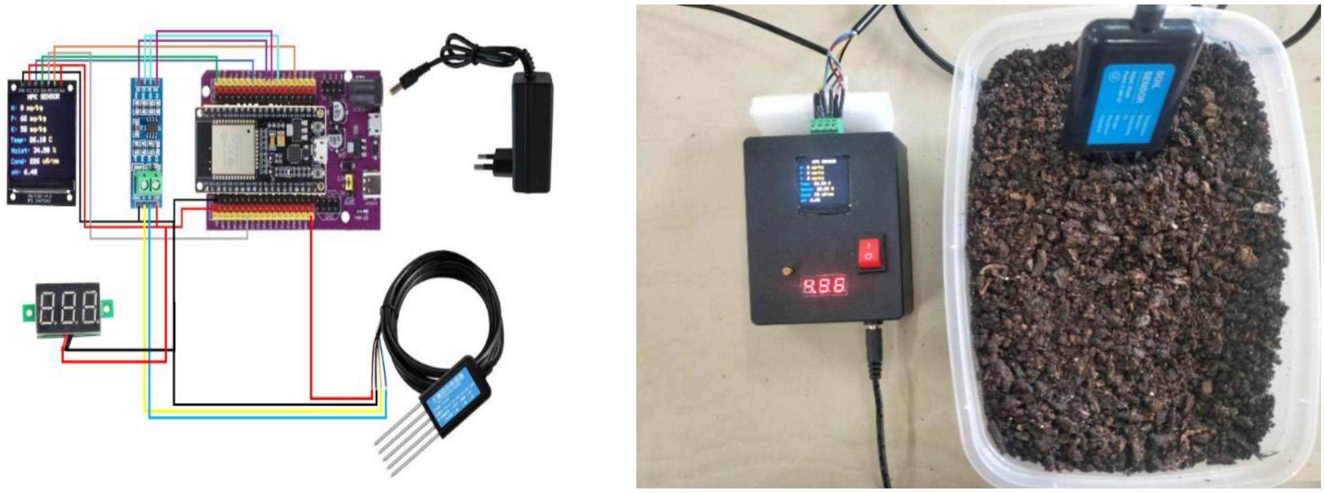

Figure 3. Application of technology (T) and engineering (E) aspects in the STEM model

Figure 3, is the project design and development as a solution that students have created. Collaboratively, students link the theory obtained in class with real-world problems. The material about nutrients can be explained through the project of making NPK, pH, humidity, conductivity, and temperature applications on soil media. This tool is equipped with an NPK sensor, ESP32 microcontroller module, and several other devices. From this activity, the final product of the project reflects the concept of Technology (T) and Engineering (E) in the STEM approach. This tool is based on technology where the readings from the ESP32 are read by firebase and continued reading by a computer or smartphone.

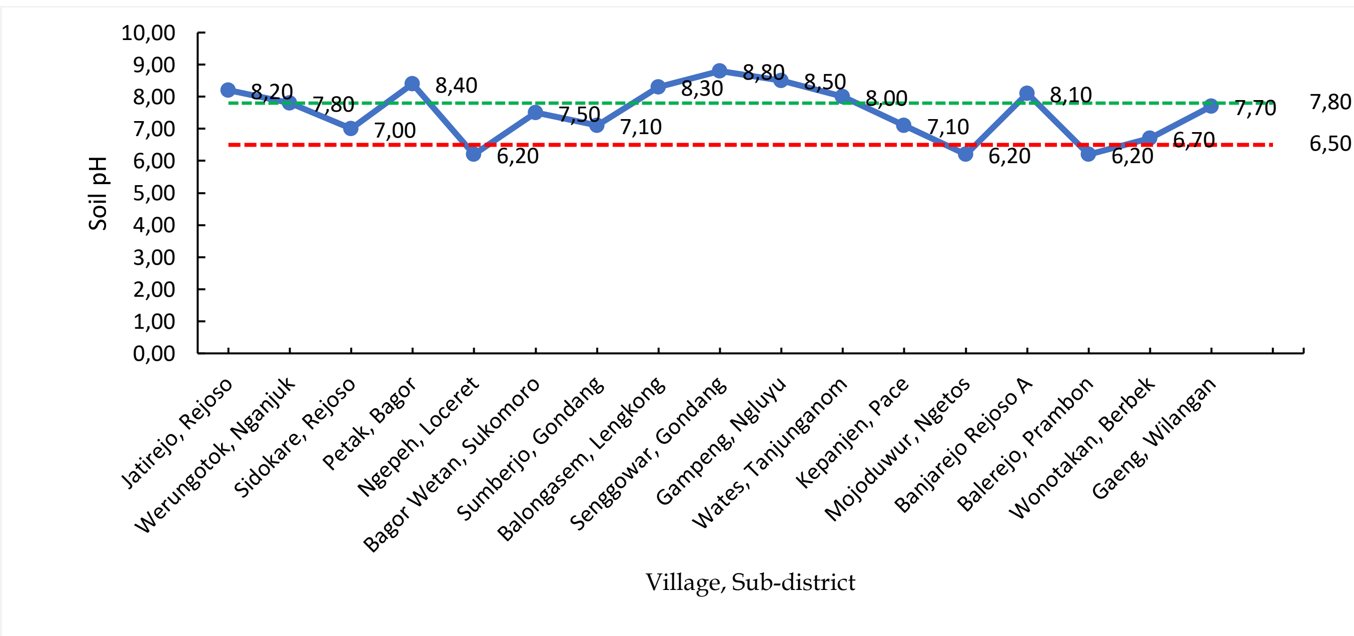

Figure 4. Results of student experiments on soil pH in Nganjuk District

Figure 4 shows the results of students' investigation and data analysis from a series of projects. In the STEM concept, this is an example of evidence of the application of Mathematics (M). The figure shows that in discussing the material on the effect of pH on the quality of nutrients, especially soil. The data was taken from 16 sub-districts in Nganjuk Regency, East Java, Indonesia with soil samples specifically for shallot cultivation. The analysis results showed that the pH of the soil ranged from 6.20 to 8.80. The final stage of the activity was reflection and evaluation. The project that has been made along with the research results in the form of data is presented to answer the initial problem. At this stage the learning experience, including the difficulties and successes of the students, is also reviewed.

Based on the explanation above, the steps for implementing PjBL-STEM are problem identification, project planning, exploration and investigation, design and development, presentation and communication, reflection and evaluation. At each of these stages, the PjBL model as much as possible contains elements of science, technology, engineering, and mathematics (Prajoko et al., 2023). The application of PjBL-STEM can begin with problem identification followed by project planning by linking the STEM approach. Students, with the help of lecturers, can design simple projects that are able to integrate technology-based science and engineering projects. In the process of creating a project design, it can be accompanied by an investigation of how the project can provide solutions to problems. This can be done by conducting a literature study to be able to formulate a hypothesis. The results of this investigation are finally used as the basis for developing the project into a product. The final project is then tested and applied to determine validity and feasibility. As the final stage of the application of PjBL-STEM, product presentation, reflection and evaluation if deficiencies are found so that improvements can be made.

Effect of PjBL-STEM on Science Literacy

The results of hypothesis testing based on Table 7 show that there is an effect of the application of PjBL-STEM on student science literacy. The results of the assessment of science literacy based on 4 indicators, namely content, process, context, and science attitude referring to Figure 1 also show that the experimental class has an average literacy achievement in the high category. One level higher than the control class with an average literacy achievement in the medium category. The experimental class that used a project-based STEM approach encouraged students to apply science concepts through a series of more contextualised project activities. There is a final product that makes students proud and appreciate the scientific process so that literacy skills increase (Nuraini et al., 2023). In contrast to the control class that applied the Problem Based Learning model. This model demands high independence and knowledge in problem solving. The absence of projects and final products makes learning less meaningful. Students with low ability can be left behind if they do not get adequate scaffolding (Khoiriyah & Husamah, 2018).

PjBL-STEM is able to integrate the four disciplines of science, technology, engineering, and mathematics. This makes learning more interdisciplinary and not limited to one concept focus (Sukarma et al., 2024). This certainly makes learners' understanding more holistic or comprehensive instead of a compartmentalised understanding. Learners can simultaneously understand science concepts but also learn technology, engineering, and maths. For example, in this research, soil nutrients are revealed through IoT-based learning media. Contextual and real problems such as pH and soil nutrients can be explained through media design activities. This results in increased analytical skills to science applications (Rahmania, 2021). Students become more active in exploring problems, collecting data, concluding results, and deeper understanding of science. Another thing that was found was the increase in collaboration and communication skills. Learners become accustomed to working in teams which has an impact on their communication skills and ability to present research findings. Significantly, these abilities are part of science literacy (Nur'aini et al., 2022).

In this study, the science literacy assessment was divided into 4 indicators. The first indicator related to science content was found in the form of mastery of basic science concepts on nutrient materials to explain the concepts of soil NPK, pH, humidity, temperature, and conductivity. This proves that the application of the project-based STEM approach has a positive impact, namely increasing conceptual understanding. Students are able to understand science concepts deeply by applying science concepts in a real context through projects (Miller & Krajcik, 2019).

The second indicator related to the process of science showed an increase in the aspects of the ability to conduct investigations, including designing experiments, collecting data, and critical thinking which are part of the components of science literacy. These results are in accordance with research related to the project-based STEM approach which affects investigative skills, critical thinking, collaboration and communication, learning motivation, and the ability to use tools and technology (Fang et al., 2021). In the investigation process, students have been able to formulate hypotheses, collect data, analyse results, and draw conclusions. Students are invited to think critically in dealing with complex problems, learn to evaluate information, consider various perspectives, and make decisions based on evidence. The project-based STEM approach involves group work, where students collaborate to complete the project. This certainly affects communication and teamwork skills, which are also part of science literacy (Shofiyah et al., 2022). In STEM projects, students often use modern tools and technologies, such as software, sensors or laboratory tools. This enhances the ability to use technology to support science learning. The series of activities eventually lead to an increase in learning motivation. Learning becomes more interesting and relevant for students as they can see first-hand the application of science in everyday life.

The third indicator related to the context of science is shown by students' ability to apply science in real-world issues to make decisions. In this study, students were able to analyse the quality of soil nutrients in shallot land test samples as one of the leading commodities in agriculture based on the concept of nutrients. Projects in the form of media measuring soil NPK levels, pH, humidity, temperature, and conductivity are evidence of the application of technology in the field of science that is not limited to the practicum table but can be used more broadly such as in modern agriculture. In fact, project-based STEM prepares students with the necessary skills and knowledge for the future and learns to connect between disciplines such as science, technology, engineering, and mathematics in one learning framework (Hussin et al., 2019).

The fourth indicator related to science attitude is shown from student attitudes such as curiosity and creative thinking skills. Curiosity is able to encourage students to think creatively in finding solutions to problems being faced in the project. This helps develop creativity and the ability to think outside the box (Hagtvedt et al., 2019). The project-based STEM approach makes learning meaningful, so students not only understand the concepts but appreciate the scientific process. Attitudes such as honesty in data collection become one of the positive indicators and are reflected in the engineering design process (Beier et al., 2019).

Conclusion

The results showed that the experimental class that used the project-based STEM approach was more effective in improving literacy than the control class that applied the Problem Based Learning model. This research presents the STEM approach through a project to design sensor-based learning media and IoT in the Basic Natural Science course. The product output is in the form of a NPK nutrient, pH, temperature, humidity, and soil conductivity test tool that can be applied in class experiments and can also be applied on a wider scale, for example in modern agriculture. In its application, the combination of the project-based STEM approach has the following learning steps: problem identification, project planning, exploration and investigation, design and development, presentation and communication, reflection and evaluation. At each of these stages, it produces positive outputs in improving students' science literacy, encouraging students to integrate science with real problems, training team collaboration in developing projects, training mastery of IoT-based technology, training data interpretation skills to make conclusions. The STEM approach can be directed in creating projects in the form of modern technology-based learning media. So that the accuracy of data and precision can be maximised. In addition, the results of this learning media are not only limited to the practicum table but can be utilised in solving surrounding problems.

Acknowledgments

Thank you to all parties who have helped in this research so that this article can be published.

Author Contributions

H.P. contributed to research idea guidance and conceptualization; M. contributed to media and technology development; Y.D.P contributed to project administration, investigation, and writing; T.W.M contributed to research data processing, methodology, and data validation. All authors have read and approved the published version of the manuscript.

Funding

This research activity has received support and funding from the Directorate General of Higher Education, Research and Technology of the Ministry of Education, Culture, Research and Technology of the Republic of Indonesia under the Domestic Cooperation Research scheme in 2024 with the project title ‘Analysis of Nutrient Quality and Soil pH Based on IoT in Nganjuk Regency as a Learning Media for Basic Natural Sciences’. Contract number 109/E5/PG.02.00.PL/2024 on 11 June 2024.

Conflicts of Interest

In writing this article, we sincerely declare that there is no conflict of interest that may affect the objectivity and integrity of the results.

References

Amroni, Y. S., Hidayah, N., Firmansah, D., & El Fiah, R. (2024). The Effect of the Project-Based Learning Model on the 4C Skills (Critical Thinking, Creativity, Communication, and Collaboration) of Elementary School Students. *Edunesia: Jurnal Ilmiah Pendidikan*, *5*(2), 699–713. https://doi.org/10.51276/edu.v5i2.745

Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The ınfluence of project-based STEM (PjbL-STEM) applications on the development of 21st century skills. *Journal of Turkish Science Education*, *18*(4), 798–815.

https://doi.org/10.36681/tused.2021.104

Beier, M. E., Kim, M. H., Saterbak, A., Leautaud, V., Bishnoi, S., & Gilberto, J. M. (2019). The effect of authentic project-based learning on attitudes and career aspirations in STEM. *Journal of Research in Science Teaching*, *56*(1), 3–23. https://doi.org/10.1002/tea.21465

Brusa, J. O., & Bahmani-Oskooe, M. (2020). The effect of social security on employee performance with job satisfaction as intervening variables (Study from Administrative Section of Texas Public Health Facilities). *Medalion Journal: Medical Research, Nursing, Health and Midwife Participation*, *1*(1), 23–39. https://doi.org/10.59733/medalion.v1i1.11

Cansız, N., & Cansız, M. (2019). Evaluating Turkish science curriculum with PISA scientific literacy framework. *Turkish Journal of Education*, *8*(3), 217–236. https://doi.org/10.19128/turje.545798

Demir, S. (2022). Comparison of normality tests in terms of sample sizes under different skewness and Kurtosis coefficients. *International Journal of Assessment Tools in Education*, *9*(2), 397–409. https://doi.org/10.21449/ijate.1101295

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology*, *29*, 369–385. https://doi.org/10.1007/s10956-020-09823-x

Fang, M., Jandigulov, A., Snezhko, Z., Volkov, L., & Dudnik, O. (2021). New technologies in educational solutions in the field of STEM: The use of online communication services to manage teamwork in project-based learning activities. *International Journal of Emerging Technologies in Learning (IJET)*, *16*(24), 4–22. https://doi.org/10.3991/ijet.v16i24.25227

García-Pérez, L., García-Garnica, M., & Olmedo-Moreno, E. M. (2021). Skills for a working future: How to bring about professional success from the educational setting. *Education Sciences*, *11*(1), 27. https://doi.org/10.3390/educsci11010027

Girgin, Ş., & Coştu, B. (2024). The Effectiveness of Daily-Life Oriented Project Based Learning on Students' Conceptual Understanding. *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi*, *61*, 2058–2082. https://doi.org/10.53444/deubefd.1423636

Hacker, M. (2024). Technology and Engineering in STEM Education. In *Locating Technology Education in STEM Teaching and Learning: What Does the 'T'Mean in STEM?* (pp. 125–143). Springer. https://doi.org/10.1007/978-981-97-1995-2_9

Hafizah, E. (2021). Correlation of students' environmental literacy and scientific literacy after students' involvement in wetlands-based stem educational approach. *IOP Conference Series: Earth and Environmental Science*, *758*(1), 12014. https://doi.org/10.1088/1755-1315/758/1/012014

Hagtvedt, L. P., Dossinger, K., Harrison, S. H., & Huang, L. (2019). Curiosity made the cat more creative: Specific curiosity as a driver of creativity. *Organizational Behavior and Human Decision Processes*, *150*, 1–13. https://doi.org/10.1016/j.obhdp.2018.10.007

Hussin, H., Jiea, P. Y., Rosly, R. N. R., & Omar, S. R. (2019). Integrated 21st century science, technology, engineering, mathematics (STEM) education through robotics project-based learning. *Humanities & Social Sciences Reviews*, *7*(2), 204–211. https://doi.org/10.18510/hssr.2019.7222

Juškevičienė, A., Dagienė, V., & Dolgopolovas, V. (2021). Integrated activities in STEM environment: Methodology and implementation practice. *Computer Applications in Engineering Education*, *29*(1), 209–228. https://doi.org/10.1002/cae.22324

Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2021). Developing and using multiple models to promote scientific literacy in the context of socio-scientific issues. *Science & Education*, *30*(3), 589–607. https://doi.org/10.1007/s11191-021-00206-1

Khoiriyah, A. J., & Husamah, H. (2018). Problem-based learning: Creative thinking skills, problem-solving skills, and learning outcome of seventh grade students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *4*(2), 151–160. https://doi.org/10.22219/jpbi.v4i2.5804

Krajcik, J., Schneider, B., Miller, E. A., Chen, I.-C., Bradford, L., Baker, Q., Bartz, K., Miller, C., Li, T., & Codere, S. (2023). Assessing the effect of project-based learning on science learning in elementary schools. *American Educational Research Journal*, *60*(1), 70–102. https://doi.org/10.3102/00028312221129247

Markula, A., & Aksela, M. (2022). The key characteristics of project-based learning: how teachers implement projects in K-12 science education. *Disciplinary and Interdisciplinary Science Education Research*, *4*(1), 2. https://doi.org/10.1186/s43031-021-00042-x

Miller, E. C., & Krajcik, J. S. (2019). Promoting deep learning through project-based learning: A design problem. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 7. https://doi.org/10.1186/s43031-019-0009-6

Muslih, M., Supriyanto, R. M. T., & Sembiring, M. G. (2023). The Effect of Teacher Pedagogic Competence and Discipline on the Performance of Elementary School Teachers during the Covid-19 Pandemic. *Edunesia: Jurnal Ilmiah Pendidikan*, *4*(2), 543–559. https://doi.org/10.51276/edu.v4i2.387

Mutanga, M. B. (2024). Students' Perspectives and Experiences in Project-Based Learning: A Qualitative Study. *Trends in Higher Education*, *3*(4), 903–911. https://doi.org/10.3390/higheredu3040052

Nur'aini, D. A., Kusairi, S., & Ali, M. (2022). Impact of The STEM approach with formative assessment in PjBL on students' critical thinking skills. *Journal of Physics: Conference Series*, *2165*(1), 12044. https://doi.org/10.1088/1742-6596/2165/1/012044

Nuraini, N., Asri, I. H., & Fajri, N. (2023). Development of project based learning with steam approach model integrated science literacy in improving student learning outcomes. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1632–1640. https://doi.org/10.29303/jppipa.v9i4.2987

Ortiz-Revilla, J., Adúriz-Bravo, A., & Greca, I. M. (2020). A framework for epistemological discussion on integrated STEM education. *Science & Education*, *29*(4), 857–880. https://doi.org/10.1007/s11191-020-00131-9

Owens, A. D., & Hite, R. L. (2022). Enhancing student communication competencies in STEM using virtual global collaboration project based learning. *Research in Science & Technological Education*, *40*(1), 76–102. https://doi.org/10.1080/02635143.2020.1778663

Prajoko, S., Sukmawati, I., Maris, A. F., & Wulanjani, A. N. (2023). Project based learning (pjbl) model with stem approach on students' conceptual understanding and creativity. *Jurnal Pendidikan IPA Indonesia*, *12*(3), 401–409. https://doi.org/10.15294/jpii.v12i3.42973

Purwaningsih, E., Sari, S. P., Sari, A. M., & Suryadi, A. (2020). The effect of STEM-PJBL and discovery learning on improving students' problem-solving skills of impulse and momentum topic. *Jurnal Pendidikan IPA Indonesia*, *9*(4), 465–476. https://doi.org/10.15294/jpii.v9i4.26432

Rahmania, I. (2021). Project based learning (PjBL) learning model with STEM approach in natural science learning for the 21st century. *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, *4*(1), 1161–1167. https://doi.org/10.33258/birci.v4i1.1727

Ramli, M., & Susanti, B. H. (2022). Indonesian students' scientific literacy in islamic junior high school. *International Journal of STEM Education for Sustainability*, *2*(1), 53–65. https://doi.org/10.53889/ijses.v2i1.33

Robinson, R. S. (2024). Purposive sampling. In *Encyclopedia of quality of life and well-being research* (pp. 5645–5647). Springer. https://doi.org/10.1007/978-3-031-17299-1_2337

Rohm, A. J., Stefl, M., & Ward, N. (2021). Future proof and real-world ready: the role of live project-based learning in students' skill development. *Journal of Marketing Education*, *43*(2), 204–215. https://doi.org/10.1177/02734753211001409

Samsudın, M. A., Jamalı, S. M., Zaın, A. N. M., & Ebrahım, N. A. (2020). The effect of STEM project based learning on self-efficacy among high-school physics students. *Journal of Turkish Science Education*, *17*(1), 94–108. https://doi.org/10.36681/

Santana, A. L. M., & de Deus Lopes, R. (2024). Using real-world problems and project-based learning for future skill development: An approach to connect higher education students and society through user-centered design. In *Creating the University of the Future: A Global View on Future Skills and Future Higher Education* (pp. 393–417). Springer. https://doi.org/10.1007/978-3-658-42948-5_20

Savitri, E. N., Amalia, A. V, Prabowo, S. A., Rahmadani, O. E. P., & Kholidah, A. (2021). The effectiveness of real science mask with QR code on students' problem-solving skills and scientific literacy. *Jurnal Pendidikan IPA Indonesia*, *10*(2), 209–219. https://doi.org/10.15294/jpii.v10i2.29918

Shofiyah, N., Wulandari, F. E., Mauliana, M. I., & Pambayun, P. P. (2022). Teamwork skills assessment for STEM project-based learnig. *Jurnal Penelitian Pendidikan IPA*, *8*(3), 1425–1432. https://doi.org/10.29303/jppipa.v8i3.1678

Sholahuddin, A., Anjuni, N., & Faikhamta, C. (2023). Project-Based and Flipped Learning in the Classroom: A Strategy for Enhancing Students' Scientific Literacy. *European Journal of Educational Research*, *12*(1). https://doi.org/10.12973/eu-jer.12.1.239

Sukarma, I. K., Hulyadi, H., Muhali, M., & Azmi, I. (2024). Exploration of Student Thinking Systems Through STEM-PjBL Project Based Learning in the Science Field. *Hydrogen: Jurnal Kependidikan Kimia*, *12*(3), 526–543. https://doi.org/10.33394/hjkkv12i3.12273

Susiloningsih, E., Fathurohman, A., Maharani, S. D., Fathurohman, M. F., & Nurani, D. C. (2025). Integration of STEM Approach in Science Education: Enhancing Students' Critical Thinking, Creativity, and Engagement in Elementary Schools in Palembang. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 10–19. https://doi.org/10.29303/jppipa.v11i4.10615

Tang, K. H. D. (2023). Student-centered Approach in Teaching and Learning: What Does It Really Mean? *Acta Pedagogia Asiana*, *2*(2), 72–83. https://doi.org/10.53623/apga.v2i2.218

Utami, A., Rochintaniawati, D., & Suwarma, I. R. (2020).

Enhancement of STEM literacy on knowledge aspect after implementing science, technology, engineering and mathematics (STEM)-based instructional module. *Journal of Physics: Conference Series*, *1521*(4), 42048. https://doi.org/10.1088/17426596/1521/4/042048

Wen, C. T., Liu, C. C., Chang, H. Y., Chang, C. J., Chang, M. H., Chiang, S. H. F., Yang, C. W., & Hwang, F. K. (2020). Students' guided inquiry with simulation and its relation to school science achievement and scientific literacy. *Computers & Education*, *149*, 103830. https://doi.org/10.1016/j.compedu.2020.103830

Winarni, E. W., Karpudewan, M., Karyadi, B., & Gumono, G. (2022). Integrated PjBL-STEM in Scientific Literacy and Environment Attitude for Elementary School. *Asian Journal of Education and Training*, *8*(2), 43–50. https://doi.org/10.20448/edu.v8i2.3873