26 (3), 2025, 1289-1307

Jurnal Pendidikan MIPA

e-ISSN: 2685-5488 | p-ISSN: 1411-2531
https://jpmipa.fkip.unila.ac.id/index.php/jpmipa

Development of STEM-PjBL-Based Teaching Materials to Enhance Students' Science Literacy on Acid-Base Topic

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Abstract: An essential skill for learning chemistry is science literacy, which includes attitudes toward science, the scientific method, application in practical settings, and conceptual comprehension. However, the previous research revealed that students' science literacy among Indonesian undergraduate students is still low, especially when it comes to abstract and complicated concepts like acids and bases. The study aims to develop STEM-PjBl-based teaching materials on acid acid-base topic and evaluate their effectiveness in enhancing students' science literacy. The study employs the 4D development model. The product effectiveness test was conducted at the development stage using a quasi-experimental design in the form of a one-group pretest-posttest design. The research subjects were 90 chemistry education undergraduate students who took basic chemistry courses in the 2024/2025 academic year, consisting of 3 classes. Data was gathered by a science literacy test, validation sheets, and practicality surveys for lecturers. The validity of questionnaire responses was obtained by three experts' judgment using the kappa coefficient, the practicality questionnaire was also assessed using the kappa coefficient, while the validity of data on science literacy improvement was obtained through pre-test and post-test results. The results showed that the average kappa coefficient of expert validation of STEM-PjBL-based teaching materials is 0.88 (high validity). The practicality questionnaire produced an average kappa coefficient of 0.89 (high practicality). The effectiveness test obtained an average n-gain value of 0.65 (moderate), as evidenced by student involvement in designing projects to create soft drinks from natural ingredients through the PjBL model. The designing and evaluating scientific investigations indicator (n-gain 0.67) shows the most significant improvement because students were required to systematically design experimental procedures, including problem identification, variable determination, hypothesis formulation, planning tools, materials, and work steps following scientific principles.

Keywords: teaching materials, STEM-PjBL, science literacy, acid-base.

▪ INTRODUCTION

In addition to mastering scientific concepts, graduates of higher education in the twenty-first century should also be able to think critically, be creative, collaborate with others, and communicate effectively. According to the OECD (2018), science literacy includes the capacity to apply scientific knowledge to explain phenomena, assess and plan scientific studies, and scientifically analyze data and evidence in social, personal, and international contexts. Science literacy encompasses critical thinking and responsible decision-making in addition to conceptual understanding (Holbrook, 2009; Norris, 2003). Science literacy, on the other hand, is the capacity to comprehend scientific and technological concerns that impact one's own and society's lives (Laugksch, 2000). As the main goal of science education, science literacy aims to help people comprehend the scientific community and engage in active social participation (Sadler, Fowler, & Tobias, 2016; Valladares, 2021). Therefore, science literacy is a competency that includes scientific conceptual understanding, scientific thinking abilities, and the capacity to use science in everyday situations to make informed decisions on a social and personal level.

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DOI: http://dx.doi.org/10.23960/jpmipa.v26i3.pp1289-1307
Received: 13 June 2025
Accepted: 06 July 2025
Published: 24 July 2025

In the context of chemistry, scientific literacy is one of the most essential abilities that students must acquire, which enables them to comprehend, rationalize, and apply scientific ideas in daily life as well as make judgments based on facts.

Meanwhile, many studies reveal that Indonesian undergraduate students' science literacy is still at a concerning level. According to the Ministry of Education and Culture's national exams in 2021 and the PISA report (OECD, 2018), most students struggle to conceptually explain scientific phenomena and find it challenging to connect science to everyday life. Students studying chemistry at a number of Indonesian universities demonstrate a poor understanding of fundamental scientific ideas and have difficulty applying them to explain contextual events (Rahayu, Suwono, & Saputro, 2020). In addition, only 35% of prospective chemistry teacher students scored high on the PISA-based science literacy index (Ismail, Fadillah, & Taufik, 2021). The majority of pupils can not plan basic scientific experiments and are unable to connect chemical ideas to social and environmental concerns. Similar to this, a previous study by Indana & Sari (2022a) demonstrates that students continue to struggle with science literacy skills, including interpreting data, solving scientific problems, and making decisions in practical settings. Less creative teaching strategies and a lack of integration between scientific ideas and real-world applications in instructional materials are factors contributing to pupils' poor level of scientific literacy (Ramnarain & Schuster, 2024; Muhammad & Yusuf, 2023).

This problem is also found specifically in chemistry learning, especially in the abstract, complex, and misconception-prone acid-base topic (Calik, Kolomuc, & Karagolge, 2010a; Herga, Grmek, & Dinevski, 2015). Preliminary research on learning in the chemistry education program at Universitas Negeri Medan indicates that students often memorize concepts without understanding how to apply them and struggle to formulate scientific arguments about acids and bases. This topic requires conceptual understanding, scientific thinking skills, and the ability to apply the knowledge in everyday life contexts, which students often have not yet mastered optimally. This problem illustrates the gap between the need for students to learn in an active, contextual, and problem-solving way and the traditional teaching methodology, which still places a strong emphasis on lecturers. In reality, students must be able to integrate various academic disciplines to address real-world problems in facing today's global challenges.. As a result, creative solutions are required, such as creating instructional materials based on a methodology that can connect theory and practice and support the all-encompassing growth of students' science literacy.

One potential solution is to integrate the PjBL paradigm with a STEM approach. Through interdisciplinary integration, the STEM approach enables students to connect chemistry ideas to real-world situations, while PjBL offers opportunities for collaborative learning through demanding and relevant projects. STEM education is currently a well-known strategy among educators due to the growing global technological perspective of the 21st century (Shernoff, Sinha, Bressler, & Ginsburg, 2017). The STEM-based learning approach has been shown to promote science literacy, critical thinking, and problem-solving skills (Nilyani, Asrizal, & Usmeldi, 2023; English, 2016; Thibaut et al., 2018). However, the project-based learning paradigm allows students to study in a context, actively, and cooperatively (Bell, 2010a). Project-based learning is an effective means of improving basic science education and STEM education (Chen & Tippett, 2022;

Kim & Kim, 2021; Viro, Lehtonen, Joutsenlahti, & Tahvanainen, 2020). Projects often begin with questions chosen by students or posed by teachers (Wijnia, 2021). The combination of the two, STEM-PjBL, is an innovative approach in contemporary science education.

Prior research has demonstrated that PjBL and STEM-based learning strategies, whether combined or used independently, can improve students' science literacy, especially when it comes to chemistry learning, which calls for advanced critical thinking, interdisciplinary connections, and practical application. Students' scientific literacy in organic compounds can be improved by using integrated STEM-PjBL instructional materials, which are worth 0.46 n-gain (Dibyantini, Amdayani, Siregar, & Syafriani, 2023). Integrated STEM PjBL supported by a science encyclopedia significantly improves scientific literacy (moderate), leading to high achievements in science education (Badaruddin, 2024; Sukri, Purwanto, & Kustiono, 2020;Anazifa & Djukri, 2017). PjBL-ethnoSTEM applied to the experimental group can improve science literacy better than learning conducted in the control group (Sumarni & Wahyuni, 2024). STEM-PjBL learning with BAJARDI is highly effective in improving student science literacy (Ricka, Santoso, & Dewi, 2023). Additionally, Haryani, Kuswanti, & Widodo, (2021); Kurniawati, Saputro, & Mahardika (2020) demonstrated that STEM-PjBL-based chemistry instructional materials can enhance students' capacity for scientific project creation, methodical thought, and assessment of the scientific influence on society, which are critical components of science literacy.

This study has significant novelty compared to previous studies. Verma (2022) developed high school students' critical thinking skills through a STEM-PjBL-based detergent waste treatment project on acid-base material, focusing on environmental aspects and using a qualitative approach at the secondary education level. Meanwhile, Musahal, Rahmawati, Purwanto, & Mardiah (2024) highlights the use of outreach initiatives and the 5E discovery-based learning paradigm to improve the STEM literacy of minority students in secondary schools on acid-base material. Although several previous studies have examined the application of STEM or PjBL separately, there have not been many studies that specifically develop STEM-PjBL-based teaching materials focused on strengthening science literacy in higher education, particularly on the concepts of acids and bases. Compared to the study of Dibyantini et al. (2023), which focuses on the organic compound topic, the acid-base topic contributes more significantly to creativity in the context of science literacy development through the STEM-PjBL approach. This is because acid-base concepts are more closely related to the everyday lives of students, such as in food products, cleanliness, health, and the environment, which opens up more opportunities for pertinent and useful scientific research. Furthermore, the idea of acids and bases includes both qualitative (like reactivity and natural indicators) and quantitative (like pH, ion concentration, and titration) components, allowing for a more thorough multidisciplinary integration within the STEM approach. This material is a good starting point for learning how to plan and assess scientific studies because it is conceptually demanding and contains typical fallacies that call for higher-order thinking abilities to overcome. Therefore, compared to earlier research, the incorporation of the acid-base topic in STEM-PjBL teaching materials not only improves science literacy but also gives greater pedagogically and contextually unique value.

Based on this background, this research is important to address the need for learning innovations that are relevant to the challenges of the times and support the achievement of student competencies in the field of science. Therefore, the question to be answered in this study is: how does the process and outcome of developing STEM-PjBL-based teaching materials improve students' science literacy in basic subjects in higher education?.

▪ METHOD

Participants

This study was conducted in the chemistry department of the chemistry education study program at Universitas Negeri Medan, Indonesia. The population of the study was all students who took basic chemistry courses in the even semester of 2024/2025. The study's samples were selected using purposive selection techniques by considering the qualities of the lecturers and the academic abilities of the students. Ninety students from three different classes (A, B, and C) participated in this study. The assumption regarding the similarity of students' abilities was based on initial grade data from the prerequisite course (General Chemistry) and institutional academic records indicating homogeneity in academic backgrounds across classes. The lecturers in all three classes had relatively similar backgrounds and pedagogical methods; it was expected that there would not be any significant differences in instructional treatment that could influence the research findings.

Three media specialists and three material experts made up the panel of experts that validated this study. Experts in their disciplines, the team consisted of academics from the Chemistry Department of Universitas Negeri Medan. While the media specialists taught learning media courses, the material experts were lecturers in physical chemistry and chemistry education.

Research Design and Procedures

This study used the research and development (R&D) method. The goal of research and development is to create products and evaluate their efficacy (Halaskova, Gavurova, & Kocisova, 2020). Thiagarajan (1974) created the 4D model, which is the model utilized in this study. It has four stages: define, design, develop, and disseminate (see Figure 1). Using a one-group pretest-posttest design, a quasi-experimental design, the product's efficacy was evaluated during the develop stage.

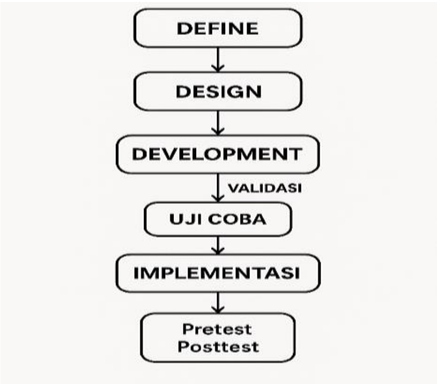

Figure 1. Flowchart of 4D model

The study was carried out in the even semester of the 2024–2025 academic year. Students were given a pretest at the first meeting to measure initial skill. STEM-PjBL-based teaching materials were used to carry out learning in the second and third meetings, each with a duration of 3 credits (equivalent to 150 minutes) per meeting. The second and third meetings were carried out on projects consisting of making carbonated drinks from natural materials, acid-base indicators from natural materials, and environmentally friendly detergents made from used cooking oil. In the third meeting, the project results were presented in class. At the fourth meeting, a posttest was conducted to determine the improvement of student learning outcomes. Thus, the total number of meetings for the whole is four meetings with a total duration of 600 minutes. The first step in applying the PjBL model with STEM-PjBL-based teaching materials is "determining the fundamental question," in which the lecturer helps students create real-world contextual problems about the idea of acid-base. An example of a fundamental question asked is 'how can we design and make carbonated drinks from natural ingredients such as galangal, Chinese lemon, and red roselaf that are healthy, attractive, and reflect an understanding of acid-base reactions? How can the acidic properties of galangal, chinese lemon, and red rosela affect the flavor and carbonation level of the drink?. Additionally, in order to address these questions, students work together to create experimental plans or products based on STEM during the "designing project planning" phase. Setting realistic deadlines, task division, and activity stages are all part of the third phase, "developing a schedule." Then, through discussion, criticism, and critical reflection on the application of STEM concepts, lecturers offer support and process evaluation during the "monitoring project progress" phase. Students present the project and use scientific data to test the outcomes or products during the "testing results" phase. Lastly, individual and group reflections on the conceptual understanding, scientific work processes, and the advancement of scientific literacy attained during project implementation are used to carry out the "evaluating the learning experience" phase.

In the project to produce carbonated drinks from kencur, chinese lemon, and red rosella, the STEM aspects designed by students contributed to improving science literacy because each STEM aspect encourages understanding, application, and communication of scientific concepts in a real-world context. In the science aspect, students learn about acid-base concepts from chemical reactions that produce carbonation. Students observe scientific phenomena such as the formation of CO2 gas from the reaction of citric acid from chinese lemon and sodium bicarbonate. This activity trains students' ability to explain scientific phenomena based on the concepts they have learned. In the technology aspect, students use tools such as digital pH meters and thermometers to observe the beverage production process. Through technology, students also develop the ability to interpret data and scientific evidence more accurately, as well as improve their scientific communication skills in presenting experimental results through digital media such as PowerPoint presentations, videos, and project reports. In the engineering aspect, students design the beverage production process from material selection, methods, and product packaging. This activity requires students to design and evaluate scientific investigations, including controlling variables, repeating experiments, and conducting data-based evaluations. In the mathematics aspect, students engage in measurement activities, concentration calculations, volume comparisons, and graphical analysis of experimental results. These skills support the ability to interpret data quantitatively, draw conclusions based on evidence, and present scientific information in a visually understandable format.

Instrument

Interview guidelines, validation sheets, practicality sheets, and science literacy test questions used as pretests and posttests are the research instruments. The lecturers were interviewed in order to examine the issues. Expert validators provided evaluations and recommendations for STEM-PjBL-based instructional materials via the validation sheet. Six professional media and material validators from among university lecturers participated in this study to assess the appropriateness of STEM-PjBL-based instructional materials. The six validators involved were professional lecturers with doctoral degrees and expertise in chemistry education, curriculum and teaching, and learning technology. They were selected based on their academic track record and experience in research and development of STEM-based learning media and project-based learning approaches. The lecturer provided a practicality assessment using the practicality sheet. Nine essay questions that were created based on the competency aspects of science literacy, namely, evaluating and designing scientific investigations, interpreting data and scientific evidence, and explaining phenomena scientifically, made up the pre-test and post-test questions.

Table 1. The framework and item specification of the science literacy test

No	Indicators	Explanation	Question Number
1	Explaining Phenomena Scientifically	Applying science knowledge in real life	1.4.7
2	Designing and Evaluating Scientific Inquiry	Assess and create an experimental design	2.5.8
3	Interpreting Data and Scientific Proofs	Analysis and evaluation of science information	3.6.9

Content validation (material experts) was conducted for the science literacy test instrument to ensure the suitability of the questions with the indicators being measured. The assessment was carried out by three experts using a 4-point Likert scale. An item is considered content valid if it receives an average score of $\geq$ 3.5 out of a maximum of 4. After the content validation process, the instrument was pilot-tested on 30 students who had studied the acid-base topic. Data from the pilot test were then analyzed using SPSS version 23 to test the reliability of the instrument. Cronbach's Alpha is used to measure the reliability of test results. Cronbach's Alpha is a statistical technique that is useful for determining the consistency of internal items in a test, mainly when the test uses a Likert scale or several items that aim to measure identical constructs (Taber, 2018). The selection of Cronbach's Alpha is based on its ability to estimate how well a group of items measures a single unidimensional latent construct, namely, scientific literacy. According to Nunnally (1978) an instrument is generally considered reliable if its Cronbach's Alpha value reaches 0.70 or higher. In the reliability analysis using Cronbach's Alpha, the data used were pretest data, because pretest data represent the original conditions before the intervention, free from biases related to the treatment.

Data Analysis

Data analysis covers the viability, usefulness, and efficacy of STEM-PjBL instructional resources. Kappa moments were used to analyze the practicality and validation sheet assessment results. The data analysis results were then interpreted. The science literacy exam that was created makes reference to the STEM-related PISA 2012 framework. 86-100 (very high), 76-85 (high), 60-75 (medium), 55-59 (low), and less than 55 (very low) are the percentage-based criteria for science literacy scores (Puwanto, 2010). N-Gain was used to analyze how students' science literacy improved after using STEM PjBL teaching materials (Hake, 1999). Cohen's d formula is used to determine the extent of the influence of STEM-PjBL teaching materials on improving students' science literacy. This statistic measures the magnitude of change resulting from an intervention, providing complementary information to the N-Gain test. Cohen's d is calculated by dividing the difference between the post-test and pre-test mean scores by the combined standard deviation. According to Cohen (2013) conventional benchmarks, a value of $d=0.2$ is considered a small effect, $d=0.5$ a medium effect, and $d=0.8$ or higher a large effect. These classifications enable a meaningful interpretation of the practical significance of the intervention beyond mere p-values.

▪ RESULT AND DISSCUSSION

This study created STEM-PjBL-based educational resources that are legitimate, useful, and successful in raising students' science literacy in acid-base materials using the 4D development model from Thiagarajan et al. (1974).

The define stage aims to identify and formulate learning problems and student needs for teaching materials. According to the results of the needs analysis, learning activities continue to be teacher-centered and incorporate little real-world context; there are no teaching materials that systematically integrate the STEM approach and the Project-Based Learning model; and students struggle to conceptually and practically understand the acid-base concept, which results in low science literacy. The findings of lecturer interviews and an examination of RPS documents support this, demonstrating the necessity of instructional materials that promote high cognitive engagement, active learning, and the development of science literacy. This result is consistent with the findings of (Calik et al., 2010;Indana & Sari, 2022), who stress the significance of creating teaching materials that are grounded in science literacy and context.

Nine essay questions were prepared as part of the science literacy test instruments during the design phase. Three validators content validated the science literacy questions prior to testing. Based on the prepared framework and item specification, each expert evaluated the questions' appropriateness based on science literacy indicators. According to the assessment results, all nine questions were deemed valid, and on a scale of 1 to 4, the average score of all experts was greater than 3.5. This shows that every question reflects the science literacy metrics that have been measured and aligns with the STEM-PjBL learning context and acid-base material content. Cronbach's Alpha was used to assess the instrument's reliability based on the findings of a trial involving thirty students. Based on Peterson & Kim (2018) interpretation, the calculation results indicate that the reliability coefficient ($r\alpha$) is 0.87, which is categorized as very high (≥ 0.80). This suggests that all of the questions are reliable indicators of science literacy and have strong internal consistency. It can be inferred that the developed essay question instrument is appropriate for use as an evaluation tool in this study due to its high reliability and expert-confirmed validity.

Furthermore, the structure of STEM-PjBL teaching materials is designed to contain integration of science, technology, engineering, and mathematics aspects explicitly in the learning project, real problem-based project activities such as “making carbonated drinks from natural ingredients”, performance-based assessments that measure science literacy, including explaining scientific phenomena, evaluating scientific inquiry, and interpreting data. Both digital and printed teaching materials were created, complete with project worksheets, assessment rubrics, and experimental guides. For objectives, activities, and evaluation to complement one another, this step adheres to the instructional alignment principle (Biggs, 1996; Harden, 2001; Wang, 2017). The STEM-PjBL teaching materials on acid-base materials are designed as follows, as seen in Figure 2.

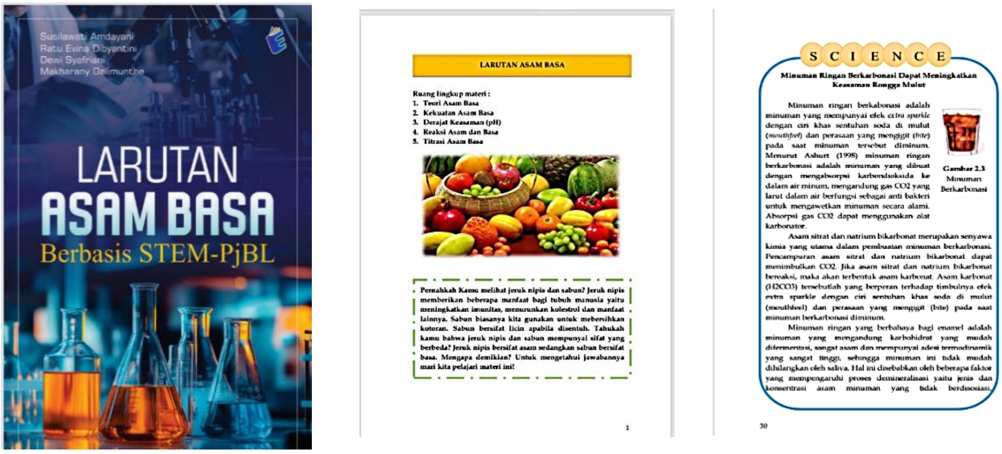

Figure 2. Teaching material design

Additionally, the developed educational resources are validated during the development stage. Expert validation of the content and media was done to determine the viability of STEM-PjBL teaching materials. The expert validation of the content showed that the STEM-PjBL educational resources were feasible to use, with an average kappa moment of 0.87 (very high). Table 2 displays the findings of the validation of every assessment component.

Table 2. Material expert validation assessment analysis results

Assessment Aspect	Average Momen Kappa
Curriculum conformity	0.89
Material accuracy	0.91
Clarity of evaluation	0.81
Accuracy of material presentation	0.91
Language compatibility	0.85
Conformity with science literacy	0,91
Material relevance with the STEM approach	0.83
Average	0.87

Table 2 above indicates that every component of the evaluation has a kappa moment value ≥ 0.81, which falls into the category of "almost perfect agreement" according to

(McHugh, 2012). The average kappa value of 0.87 indicates that validators are very consistent in assessing the quality of educational resources.

The aspects of material accuracy, material presentation, and compatibility with science literacy received the highest scores (0.91), indicating that the teaching materials were prepared with scientific concepts accurately and presented in a way that promotes science literacy. Although the evaluation's clarity (0.81) and connection to the STEM approach (0.83) received the lowest scores, they were still categorized as having "almost perfect agreement," meaning that only slight adjustments are required to improve the evaluation tools' clarity and further solidify the integration of STEM elements.

The teaching materials were also evaluated by media experts. The quality of the visual appearance and design of STEM-PjBL-based teaching materials was evaluated through validation by media specialists. The evaluation takes into account a number of significant factors that influence how appealing, readable, and comfortable instructional materials are for users. Table 3 displays the result of the media expert validation assessment.

Table 3. Media expert validation assessment analysis results

Assessment Aspect	Average Momen Kappa
Cover	0.80
Layout	0.96
Picture and illustration	0.95
Colour	0.83
Average	0.89

Based on Table 3, the layout and illustration aspects obtained a very high kappa value (≥ 0.95), which indicates that the teaching materials have a systematic layout and illustrations that support content understanding very well. This is in line with Branch (2009) learning design guidelines, which state that a well-organized visual structure can increase learning absorption and interest.

The color and cover aspects also showed a high level of agreement (≥ 0.80). The kappa value for the cover aspect is 0.80 in the substantial suitability category, meaning that it can still be improved in terms of aesthetics or initial attractiveness. The colors used are considered quite harmonious and support readability, in accordance with the principles of educational visual design. The colors used are considered quite harmonious and support readability, in accordance with the principles of educational visual design (Ozdamli & Ozdal, 2018; Wong, 2016; Liu, Liu, & Wang, 2020). This teaching material can be deemed highly feasible in terms of appearance and learning support media because its average kappa moment value is 0.89, falling into the category of nearly perfect agreement.

According to the findings of the validation analysis of STEM-PjBL-based teaching materials conducted by media and material experts, the average Kappa moment value is 0.88, falling into the category of "almost perfect agreement" (McHugh, 2012). This shows that the teaching materials developed have met the eligibility criteria both in terms of content substance and visual appearance. All aspects of the assessment received high scores, indicating that the teaching materials have been designed with a strong pedagogical and scientific foundation.

Meanwhile, media expert validation assesses aspects such as cover, layout, illustrations, and color combinations. The results show that the visual design of teaching materials is very good, attractive, and supports readability and student involvement in the learning process. Therefore, it can be said that the teaching materials created are declared “very valid” and appropriate for use in the classroom as a means of enhancing students' scientific literacy using the STEM-PjBL approach.

Furthermore, the practicality test was carried out on the lecturers who taught the course as many as seven people. Assessment of the practicality of educational resources was carried out by lecturers who taught the course through three leading indicators, namely ease of use, estimated learning time, and benefits. The following is the average value of the kappa moment from 7 lecturers for each indicator seen in Table 4.

Table 4. Assessment of lecturer practicality

Assessment Aspect	Average Momen Kappa
Ease of use	0.91
Estimated Learning Time	0.85
Benefits	0.91
Average	0.89

In the aspect of ease of use, the kappa moment value is 0.91, which shows a very high level of agreement between assessors that teaching materials are easy to use by lecturers in the learning process. This reflects that the presentation format, content structure, and instructions on teaching materials are well designed and support the implementation of efficient and intuitive learning (Nieveen, 2007;Akker, Gravemeijer, McKenney, & Nieveen, 2013). The kappa moment value of 0.85 is in the high category, indicating that the estimated learning time required to use the teaching materials is considered realistic and in accordance with the time allocation in the learning unit. This is important to ensure the feasibility of implementation in real learning conditions in the classroom (Youhasan et al, 2021). The benefit aspect obtained a score of 0.91, indicating that the lecturers assessed that this teaching material made a significant contribution to the learning process, especially in encouraging the development of student science literacy. Teaching materials not only support the achievement of chemistry competencies, but also encourage the integration of real-world context and 21st-century skills through the STEM approach and PjBL model (Bell, 2010 ; Bybee, 2013). Based on the interpretation of the kappa moment scale from Landis & Koch (1977), scores between 0.81-1.00 are categorized in the “almost perfect agreement” category. Thus, the average kappa moment of 0.89 indicates that lecturers strongly agree that this teaching material is practical and feasible to use in learning. This high degree of applicability and validity is inextricably linked to a number of exceptional traits that have been methodically created. First, this teaching material integrates the STEM approach with the project-based learning (PjBL) model, thereby providing contextual, applicable, and challenging learning experiences. Second, the projects designed are authentic and creative, such as making carbonated drinks from natural ingredients, which not only encourage higher-order thinking skills but also improve collaboration and communication skills. Third, this teaching material is equipped with interactive media in the form of video demonstrations of experiments and project guides that make it easier for students to understand work procedures visually and contextually. Fourth, the evaluation used is HOTS-based, designed to measure students' critical, analytical, and reflective thinking skills. Finally, the visual design of teaching materials is attractive and well-structured, containing infographics and layouts that facilitate navigation and clarify the content of the material. All of these features contribute significantly to the high level of validity and practicality of teaching materials, and make them very suitable for use in learning chemistry that is innovative and relevant to the demands of the 21st century.

The next stage is disseminate, this stage is carried out to determine the effectiveness of STEM-PjBL-based teaching materials that have been developed in improving student science literacy in acid-base materials. Teaching materials were implemented in three different classes (Class A, B, and C), each consisting of 30 students. Before using STEM-PjBL teaching materials, students were given science literacy questions as a pretest, and then at the end of learning, students were also given posttest questions. Furthermore, the results of the initial and final test data were analyzed using the N-gain formula. The following is the pretest and posttest data of the three classes can be seen in Table 5.

Table 5. Pretest and posttest data of the three classes

Class	Average Pretest	Average Postest	Average N-Gain	Category
A	45.2	78.6	0.61	Moderate
B	42.5	80.1	0.65	Moderate
C	44.3	82.4	0.68	Moderate

The increase in the three classes' average scores from the pretest to the posttest, as indicated in Table 5 above, indicates that using STEM-PjBL teaching materials effectively raises students' science literacy. The average N-Gain value ranges from 0.61-0.68, which according to Hake (1999), is categorized as the medium to high category. This indicates that there is an increase in students' science literacy after following project-based learning and the STEM approach. Class C had the highest N-Gain (0.68), close to the high category. This could be due to more active student involvement in the project, classroom dynamics conducive to collaboration, and lecturer adaptation in managing the STEM-PjBL approach. This finding aligns with the research by Bell (2010) that state the application of project-based learning effectively improves learning outcomes when students are directly involved in contextual activities. Although there were differences in pretest and posttest averages between classes, the N-Gain values were relatively homogeneous and consistent in the moderate category, indicating that the teaching materials had a stable level of effectiveness across various classroom contexts. This suggests that there is good instructional reliability in the design of the teaching materials (Akker et al., 2013). By integrating the acid-base topic into real-world situations, STEM-PjBL teaching resources offer meaningful learning experiences. In addition to learning theoretical concepts, students also put them to use in practical projects like creating natural indicators or determining the acidity or basicity of household waste. This strategy is consistent with the definition of science literacy, which emphasizes students' capacity to apply scientific knowledge in real-world situations (OECD, 2018).

Analysis of Science Literacy Test Data on Competency Aspects

Analysis of pretest and posttest scores for science literacy indicators in the competency aspect is to explain scientific phenomena, designing and evaluate scientific inquiry, and interpret data. The results of the analysis of each indicator of student science literacy in classes A to C are presented in Tables 6 to 8.

Table 6. Analysis of pretest and posttest scores in class A

Science Literacy Indicators	Average Pretest	Average Postest	N-Gain	Category
Explaining Phenomena Scientifically	46	77	0.57	Moderate
Designing and Evaluating Scientific Inquiry	44.5	79	0.62	Moderate
Interpreting Data and Scientific Proofs	45.2	79.8	0.64	Moderate
Average	45.2	78.6	0.61	Moderate

Table 6 shows the average results of the pretest and posttest of science literacy of class A based on three leading indicators. There was an increase in scores on all indicators after learning using STEM-PjBL-based teaching materials. The pretest scores ranged from 44.5 to 46.0, while the posttest scores showed a significant increase, with a range of 77.0 to 79.8. This increase was measured using N-Gain, which was in the moderate category for all indicators, with the highest value in the indicator of interpreting data and scientific evidence (N-Gain = 0.64). The significant increase in posttest scores compared to the pretest, accompanied by an average N-Gain value of 0.61 in the moderate category, indicates the effectiveness of STEM-PjBL-based teaching materials in improving students' science literacy skills. This finding is in line with the results of research conducted by Muskania, Maksum, & Astra (2023) which shows that the STEM-PjBL approach can improve students' science literacy through project-based activities that are relevant to real-life contexts.

Table 7. Analysis of pretest and posttest scores in class B

Science Literacy Indicators	Average Pretest	Average Postest	N-Gain	Category
Explaining Phenomena Scientifically	41.0	78.2	0.63	Moderate
Designing and Evaluating Scientific Inquiry	43	81	0.67	Moderate
Interpreting Data and Scientific Proofs	43.5	81.1	0.66	Moderate
Average	42.5	80.1	0.65	Moderate

Based on Table 7 above, it can be seen that the average results of the pretest and posttest of class B science literacy also increased scores on all indicators after learning using STEM-PjBL-based teaching materials. This increase is illustrated in the N-Gain value, which ranges from 0.63 to 0.67 and is in the moderate category. The highest N-Gain value was found in the indicator evaluating scientific inquiry (0.67), followed by interpreting data (0.66), and explaining scientific phenomena (0.63). The overall average N-Gain of 0.65 indicates that the learning approach used is quite effective in improving students' science literacy consistently on these three indicators. STEM-PjBL in improving students' science literacy skills. This finding is in line with the research results of Putri et al. (2021), which show that the STEM-PjBL approach is able to improve scientific skills through direct experience in designing and evaluating investigations.

Table 8. Analysis of pretest and posttest scores in class C

Science Literacy Indicators	Average Pretest	Average Postest	N-Gain	Category
Explaining Phenomena Scientifically	43.5	81	0.66	Moderate
Designing and Evaluating Scientific Inquiry	44	84	0.71	High
Interpreting Data and Scientific Proofs	45.4	82.2	0.69	Moderate
Average	44.3	82.4	0.68	Moderate

Table 8 shows the pretest and posttest results of class C. The average pretest score of students was low, ranging from 43.5 to 45.4. After the learning intervention, the posttest scores increased significantly, with a range of 81.0 to 84.0. The highest N-Gain value was found in the indicator evaluating scientific inquiry at 0.71 (high category), followed by interpreting data at 0.69, and explaining scientific phenomena at 0.66, both in the medium category. The overall average N-Gain was 0.68, which is in the medium category and close to high. These results indicate that the applied learning approach encourages students to understand and apply scientific concepts more deeply, especially in the context of investigation and data analysis. The significant increase in the indicator of evaluating scientific inquiry reflects the active role of students in the process of experimentation and project-based problem solving. This finding is in line with the research of Fitriyani, Toto, & Erlin (2020) which showed that the STEM-PjBL approach can significantly improve scientific inquiry skills through exploratory and contextual learning experiences.

The increase in science literacy obtained was also higher than the results of the study by Dibyantini et al. (2023), which reported a lower average N-gain in the context of implementing the STEM-PjBL. This difference can be examined from several aspects, including the context of the material used, the duration of the intervention, and how the PjBL model was implemented in the learning process. In this study, the materials were designed contextually with a STEM-PjBL approach that allows students to link chemical concepts with real-world problems more actively. In addition, the duration of learning is carried out intensively in 4 meetings with an emphasis on the full cycle of projects, ranging from problem identification, solution design, to presentation of results, so as to provide sufficient time for students to develop deeper conceptual understanding. Meanwhile, in the study by Dibyantini et al. (2023), although they also implemented STEM-PjBL, limitations in the duration of implementation and student involvement in project decision-making seemed to affect the effectiveness of learning. Therefore, the higher N-gain advantage in this study can be attributed to a more holistic, integrative learning design that provides more space for exploration and collaboration.

Based on the results in the three tables above, there was a consistent improvement in all indicators of students' science literacy after participating in STEM-PjBL-based learning. The following are the average pretest, posttest, and N-gain results for each indicator, as shown in Figure 2.

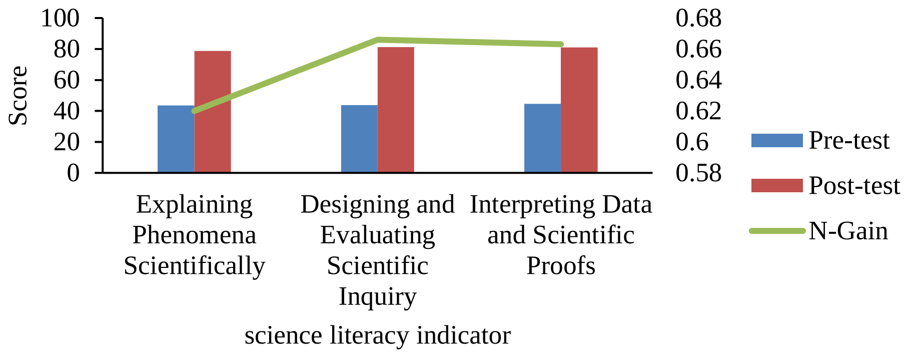

Figure 2. Pretest, Posttest, and N-Gain value for each science literacy indicator

Figure 2 shows that the indicator explaining scientific phenomena has the lowest increase, with an n-gain value of 0.62. This value indicates that although the teaching materials developed have been able to improve student understanding, the ability to explain scientific phenomena in depth and conceptually is still not optimal. This may be due to several factors, such as the tendency of students to focus more on the technical aspects of the project (e.g., practical stages or final products) compared to the scientific conceptualization process behind the observed phenomena. Furthermore, it is possible that learning activities have not fully stimulated reflective discussions or explicit exploration of the theories underlying the phenomena observed in their projects. To strengthen this aspect, teaching materials can be revised by adding conceptual scaffolding activities, such as worksheets that guide students to identify, analyze, and explain scientific principles that occur during the project process. For example, when making carbonated drinks, students are explicitly directed to explain the acid-base reaction process and the formation of CO_2 gas from a chemical point of view. Class discussions based on open-ended questions, case studies, and the use of infographics or interactive simulations depicting microscopic phenomena (e.g., ionic reactions) can also help students relate abstract concepts to their real-life experiences. In addition, it is necessary to add special formative evaluation questions that assess the extent to which students are able to explain cause-and-effect relationships in the phenomena studied. With these reinforcements, it is expected that students' ability to explain scientific phenomena can improve more significantly in the implementation of teaching materials in the future. The indicator evaluating scientific inquiry showed the highest increase with an N-Gain value of 0.67. This increase can be explained by the characteristics of the STEM-PjBL approach, which directly places students in real project-based problem-solving situations, thus requiring them to design, implement, and evaluate scientific processes actively. This is in line with the findings of Mulyani & Arif (2021), who stated that direct involvement in projects improves students' metacognitive abilities in evaluating scientific processes. This finding suggests that students' ability to organize and carry out scientific research has considerably increased. One of the activities in the teaching materials that is directly related to this improvement is the task of designing an experiment to make carbonated drinks using natural ingredients like Chinese lemon, galangal, and red roselle leaf. In order to complete this task, students had to design their experiment. This included defining the goals of the experiment, determining the independent variables (such as the kind of natural ingredients), the dependent variables such as the flavor or degree of carbonation, and the control variables such as temperature, solution volume, and observation time. They were not only expected to follow a predetermined procedure.

Additionally, students directly create data collection strategies, from choosing suitable measurement methods to planning experimental procedures to creating data recording formats. As students are forced to consider the viability of their designs critically, make adjustments in light of observations, and assess the efficacy of the employed strategy, this process directly develops their inquiry skills. Through the Project-Based Learning (PjBL) approach, students are encouraged not only to be consumers of knowledge who passively receive information, but also producers and evaluators of investigation designs. They are given the space to make scientific decisions independently, face and solve problems that arise during experiments, and reflect on the quality of the data and conclusions produced. Thus, PjBL inherently trains metacognitive and reflective skills that are essential in building 21st-century science literacy.

▪ CONCLUSION

The results of this study indicate that the development of STEM-PjBL-based teaching materials on acid-base materials can significantly improve students' science literacy. The learning approach that combines STEM principles and real problem-based projects successfully creates a more contextual, interactive, and meaningful learning experience. In addition to strengthening understanding of chemical concepts, students are also actively involved in the process of scientific inquiry that encourages critical and collaborative thinking skills. This finding is an important contribution in answering the main problem raised in this study, namely, the low science literacy among students, especially in understanding and applying the concept of acid-base in a real context

However, some limitations need to be acknowledged so that the results of this study can be interpreted more proportionately. Firstly, the design of the study without a control group limits the ability to conclusively isolate the effect of the intervention, as there was no neutral comparison of changes in learning outcomes. Secondly, since the study only involved students from one study program, the results cannot be generalized to student populations from other study programs. Third, the measurement of science literacy was carried out only shortly after the intervention, so the long-term effects of using this teaching material on science literacy cannot be known. Fourth, there are differences in learning facilitation by lecturers; if different lecturers teach the three classes, it has the potential to become a confounding variable that affects the results, especially if the teaching style or level of support provided is not uniform.

As a practical implication, the results of this study recommend that educators begin to integrate the STEM-PjBL approach in teaching materials, especially for chemistry topics that demand conceptual understanding and application in everyday life. For further development, future research can focus on more specific learning strategies to strengthen science literacy aspects on the indicator of explaining scientific phenomena. Strategies that can be applied include the use of scaffolded explanation tasks, where students are trained to relate chemical concepts to everyday phenomena through trigger questions, conceptual models, and scientific argument-based discussions. In addition, the use of visual simulations and augmented reality can help students connect concept abstractions with reality, so that they more easily interpret and explain the phenomena they observe. Further studies with a more robust experimental design, involving a control group, longer learning duration, as well as involving a more diverse population, are highly recommended so that the effectiveness of this teaching material can be tested more broadly and in-depth in the context of higher education.

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