IJCER
doi: 10.20885/ijcer.vol10.iss1.art5
p-ISSN 2549-9947
e-ISSN 2614-1426

Effect of a Using PBL-based Chemical Equilibrium E-Module on Students' Science Literacy Skills: A Quasy-Experimental Study in Indonesian High School

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Received: April 2, 2026; Accepted: April 23, 2026; Published: Apri 30, 2026

ABSTRACT: Scientific literacy is a crucial competency in modern education. However, limited studies have examined its impact on science literacy within the Indonesian Phase F curriculum context. This research seeks to investigate the effect of using a problem- based learning (PBL) e-module on chemical equilibrium on the science literacy skills of Phase F students at SMAN 9 Padang. It employs a quasi-experimental method with a non-equivalent control group design. The population consists of Phase F students at SMAN 9 Padang, while the sample includes Class XI F3 (27 students) and Class XI F8 (27 students). The samples were selected through purposive sampling to meet the research criteria, namely students with relatively similar ability levels. The research instrument consisted of a test designed to measure students' science literacy abilities. Data were analyzed using N-gain calculations, normality and homogeneity tests, as well as hypothesis testing. The findings indicate that the average N-gain in the experimental group (0.55) is higher than that in the control group (0.45). The results of the normality and homogeneity tests show that the data are follow a normal distribution and are homogeneous. Furthermore, the hypothesis testing using a *t-test* revealed that the obtained t-count value (2.3781) is greater than the critical t-table value (1.6747). These findings indicate that the use of a PBL-based chemistry equilibrium e-module provides a significant effect on enhancing students' science literacy in high school.

Keywords: e-module, chemical equilibrium, problem-based learning, science literacy

INTRODUCTION

21st-century education requires students to possess literacy skills, character development, practical skills, technological proficiency, and knowledge [1]. In the global context, these competencies are essential to prepare students to face complex scientific and technological challenges in everyday life. The concept aligns with the 21st century skills framework established by the Partnership for 21st Century Skills. Based on this document, students must possess competitive skills aligned with the demands of the times, especially the 4Cs: critical thinking, communication, collaboration, and creativity, as well as competence in technology [2]. Based on Usman et al [3], scientific literacy integrates an understanding of scientific concepts with mastery of the subject matter, understanding of the scientific process, and the ability to connect science with real-world phenomena. Therefore, scientific literacy is a crucial competency for modern education. Particularly within the implementation of the Merdeka Curriculum, which emphasizes higher order thinking and problem solving skills in science learning contexts.

Data from PISA reveal that Indonesian students continue to have relatively low levels of scientific literacy, with a score of 396.1 in 2018. This score remains far below the OECD average of 489, while the 2022 PISA results report a science literacy score of only 382.9 [4]. Indonesia's PISA assessment results from 2000 to 2022 are shown in Figure 1.

Research carried out by Tekda et al [5] revealed that students' scientific literacy levels remain in the low category, with an average science literacy score of 43.2%, and the lowest achievement was in the aspect of scientific process skills, at 24.3%. Meanwhile, studies conducted in senior high schools, especially in the city of Padang, indicate that the average science literacy score based on PISA criteria is still categorized as low, with a value of 47.32, as presented in Table 1. These findings suggest that students experience difficulties in applying scientific concepts and solving contextual problems. This condition indicates a gap between expected competencies and actual student performance, especially in chemistry learning.

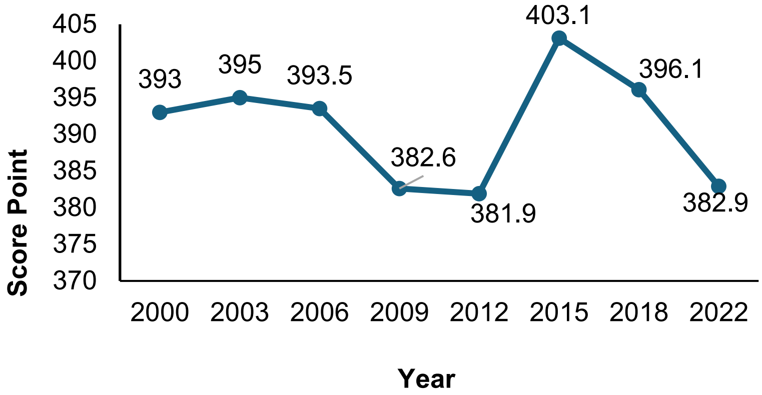

FIGURE 1. PISA Results for Indonesia, 2000–2022 [4]

TABLE 1. Assessing scientific literacy of high school students in Padang [5]

No	Senior High School	Average Score	Category	Value	Category
1.	SMAN A	36.80	Complete	57.50	Low
2.	SMAN B	29.41	Not Completed	45.90	Low
3.	SMAN C	27.87	Not Completed	43.50	Low
4.	SMAN D	27.17	Not Completed	42.40	Low
	Average	30.31	Not Completed	47.32	Low

These findings suggest that although scientific content is delivered, students still have limited understanding of scientific literacy, particularly in terms of application and problem-solving. A study carried out in a senior high school in Padang revealed that students' scientific literacy in physics had an average score of 47.48%, which is categorized as very low [6].

These low levels of science literacy also affect students' understanding of chemistry, particularly regarding the topic of chemical equilibrium taught in 11th grade Phase F. This material covers several aspects of knowledge that students need to master, namely factual, conceptual, and procedural knowledge. In the chemical equilibrium material, factual knowledge covers the course of the reaction, where equilibrium reactions are divided into reversible and irreversible equilibria. Conceptual knowledge covers the understanding that a reaction can proceed in equilibrium if there are no external influences. Furthermore, procedural knowledge is found in the application of chemical equilibrium concepts, for example, in the process of ammonia production via the Haber-Bosch process. Based on these characteristics, it can be said that the subject of chemical equilibrium is abstract in nature.

The abstract and complex characteristics of chemical equilibrium material are among the factors that make it difficult for students to learn. Studies conducted in senior high schools show that students often have difficulty understanding chemical equilibrium concepts in real-life contexts and in solving problems that require problem-solving skills [7]. This difficulty arises because students must comprehend the changes that occur during chemical reactions and identify the conditions of equilibrium, which require abstract thinking and logical reasoning. The challenge is further compounded by a learning process that relies heavily on oral instruction, limited variety in teaching materials, and underutilization of technology in learning modules. Therefore, innovative learning approaches and instructional media are needed to support students in understanding complex concepts and improving their scientific literacy.

Previous studies have shown that the Problem-Based Learning (PBL) model can effectively enhance students' scientific literacy and higher order thinking skills, for example the result of a study conducted by Aripin et al [8] indicate that the consistent use of the Problem-Based Learning (PBL) approach can enhance science literacy across various educational contexts. This model encourages students to develop creative thinking skills, foster innovative ideas, develop higher-order thinking skills, improve communication and collaboration skills, and accustom them to interacting and collaborating in problem-solving [9]. In this way, students understand the purpose of their learning, as they collect and analyze information by addressing problems through a learning approach that enables them to actively construct their own knowledge. To facilitate the learning process, instructional resources can be provided in the form of modules, which have now developed into electronic versions called e-modules. E-modules offer advantages such as animations, images, videos, and audio, all of which can enhance students' understanding of the material [10]. Furthermore, e-modules are not limited to use in schools but can also be accessed anytime and anywhere via a smartphone or laptop.

To provide a clearer conceptual foundation for the instructional approach used in this study, the key concepts underlying the integration of learning models, instructional media, and targeted competencies namely Problem-Based Learning (PBL), e-module, and scientific literacy are described as follows.

E-Module

E-modules are instructional materials systematically developed based on a specific curriculum and presented in digital format. In their presentation, e-modules provide various links for navigation, enabling students to interact more dynamically during the learning process. Moreover, e-modules are enhanced with multimedia components, including animations, instructional videos, and audio, to support and deepen students' understanding [13].

E-modules essentially share similar characteristics with printed modules. Therefore, e-modules can adapt the characteristics of printed modules while incorporating additional features that support presentation in a digital format. The first characteristic of an e-module is that it is self-instructional, meaning it is designed to facilitate students' independent learning without relying on teachers, tutors, or other learning resources. Second, it is self-contained; students do not need to seek additional materials outside the module because all content related to a single competency unit is fully integrated within the e-module. Third, "Stand-alone," meaning the e-module can be used independently and practically without needing to be paired with other media or instructional materials. Fourth, "Adaptive," meaning the e-module must be flexible to adapt to advancements in technology, scientific knowledge, and student needs. Fifth, User-Friendly, meaning that the e-module developed should adhere to the principles of ease of use and user-friendliness. Finally, Consistency, meaning that the e-module must maintain uniformity in the use of fonts, spacing, and page layout formats [14].

E-modules have several advantages and disadvantages. The advantages are: (1) e-modules can increase student motivation because assignments and materials are presented clearly and tailored to students' abilities; (2) after the evaluation process, teachers and students can accurately identify which modules have been successfully mastered and which parts still need improvement; (3) the distribution of course material is more balanced over a single semester; (4) the presentation of learning becomes more practical, interactive, and dynamic; and (5) the inclusion of tutorial videos within e-modules also helps reduce the overreliance on excessive verbal explanations, as seen in printed modules. However, e-modules also have several drawbacks, including: (1) relatively high development costs and a time-consuming creation process; (2) during learning, students may open other applications that can disrupt their concentration, thus requiring supervision from educators or facilitators [14].

Problem Based Learning (PBL) Model

TABLE 2. Stages of the Problem-Based Learning Model [15]

Syntax	Activity Description
Syntax 1: Orienting students toward the problem	The teacher conveys the learning objectives and encourages students to actively engage in the assigned problem-solving activities.
Syntax 2: Arranging Students for the Learning Process	The teacher guides students in formulating and organizing steps to solve the problems being studied.
Syntax 3: Directing Individual and Group Investigations	The teacher assists students in tasks such as information gathering, conducting experiments, and finding explanations to solve the problem being studied.
Syntax 4: Developing and presenting work products	Teachers guide students in designing and preparing their work and presenting it in relation to the topics they have studied.
Syntax 5: Analyzing and evaluating the problem-solving process (reflection)	Teachers guide students in reflecting on and evaluating the learning process.

Problem-Based Learning (PBL) is an innovative teaching model that encourages students to actively participate in the learning process by identifying problems and solving them through the application of the scientific method. As a result, students gain a stronger grasp of concept while also improving their critical thinking and problem solving abilities [9]. The steps involved in the PBL process are presented in Table 2.

The features and characteristics of PBL according to Yuantari [16] include: (1) Real-world, open-ended, and unstructured problems serve as the driving force and framework for learning; (2) Learning is conducted independently, cooperatively, contextually, and reflectively; (3) Teachers act as facilitators and providers of scaffolding (rather than direct providers of information); (4) The primary aim to strengthen students' critical thinking, teamwork, and problem solving skills through the use of knowledge from multiple disciplines.

Science Literacy

Science literacy derives from the Latin term "literatus," meaning literate or educated, and the word "science," meaning knowledge [17]. According to Catherine [18], Science literacy refers to an individual's capacity to comprehend and communicate scientific concepts verbally and in writing, apply scientific knowledge to solve problems, and exhibit a responsible attitude toward oneself and the environment in decision making.

These science competencies are divided into six competency areas, Specifically, these include: 1) providing scientific explanations for phenomena, 2) designing and assessing scientific investigations while critically analyzing data and evidence, 3) Examining, analyzing, and applying scientific data to inform decision making and behavior, 4) describing the effects of human activities on Earth systems, 5) making informed choices and taking action based on evidence evaluation and the use of creative and systematic thinking to restore and sustain the environment, and 6) showing respect for diverse perspectives and goals when addressing socio-ecological challenges [4]. Given these distinct competencies, science literacy indicators also have characteristics that differ from conventional learning indicators. Table 3 presents several science literacy indicators based on PISA 2022.

TABLE 3. Science Literacy Indicators [4]

Domain	Indicators
Explaining Phenomena Scientifically	- Retrieve and apply appropriate scientific knowledge. - Recognize, apply, and construct explanatory models and visual representations. - Develop and justify accurate predictions based on scientific principles. - Formulate scientifically grounded explanatory hypotheses. - Describe potential societal implications of scientific knowledge.
Evaluating and Designing Scientific Inquiry	- Identify investigable questions within a scientific study. - Distinguish between scientifically testable and non-testable questions. - Propose appropriate methods for investigating specific scientific questions. - Evaluate scientific approaches used to address a given problem. - Analyze how researchers ensure data reliability, objectivity, and applicability of findings.
Interpreting Data and Evidence Scientifically	- Transform data across different representation formats. - Analyze and interpret data to derive valid conclusions. - Identify assumptions, evidence, and reasoning within scientific texts. - Differentiate between arguments based on scientific evidence and those based on non-scientific factors. - Critically evaluate scientific claims and evidence from various sources, including media, online platforms, and academic publications.

Based on the concepts described above, integrating Problem-Based Learning (PBL) with e-modules provides a promising approach to support the development of students' scientific literacy. The instructional resource developed is a Problem-Based Learning (PBL) e-module on chemical equilibrium, which is integrated with the TPACK framework, which has been validated and tested for practicality by Ardiansyah & Yerimadesi [11], and tested for effectiveness by Antika & Yerimadesi [12], To date, there has been no research on how this e-module affects scientific literacy skills. In light of the positive effects of the PBL model on literacy development and its connection to science literacy. This indicates a clear research gap regarding the integration of PBL-based e-modules and their influence on scientific literacy in chemical equilibrium topics. Based on this gap, this study aims to investigate the effect of using a Problem-Based Learning (PBL)-based chemical equilibrium e-module on the scientific literacy skills of phase F students. This research is expected to provide new insights into the effectiveness of integrating PBL and digital learning media in improving students' scientific literacy, particularly in abstract chemistry concepts.

RESEARCH METHODS

This study applies a quantitative methodology, employing a quasi-experimental design with a non-equivalent control group design [19]. The participants were chosen using purposive sampling based on specific criteria, including similar academic ability levels, the same grade level (Phase F), and comparable prior knowledge based on previous chemistry scores, in order to ensure group comparability and reduce sampling bias, and comprised both experimental and control groups. The experimental group received instruction via PBL-based e-modules, whereas the control group was taught using traditional instructional materials provided by the school within the same instructional framework. Both groups completed identical pretest and posttest to assess the effects of the two teaching methods.

The research was conducted with class F students at SMAN 9 Padang in the 2025/2026 academic year. A written test developed by Sukardi [20], comprising 15 multiple-choice and 9 essay questions on scientific literacy, was used as the research instrument. The instrument was developed based on scientific literacy indicators, namely: (1) explaining scientific phenomena, (2) evaluating and designing scientific investigations, and (3) interpreting scientific data and evidence. The development of the instrument also referred to the theoretical framework of scientific literacy to ensure construct validity. An example item is: "Based on the discussion above, determine the maximum concentration of chlorine that is safe for use in children's pools. Explain it based on the graph (concentration in % volume units)!". All items were pilot-tested to ensure validity, reliability, discrimination, and appropriate difficulty levels. Furthermore, the results of validity analysis showed that all 15 multiple-choice items and 9 essay items were valid, content validity was established through expert judgment involving four chemistry education experts. The reliability test results indicated that Cronbach's Alpha was 0.92, categorized as excellent, for multiple-choice items and 0.80, categorized as good for essay items.

In this study, the independent variable was the implementation of PBL-based electronic modules, and the dependent variable in this research was the science literacy skills of students. Conducted over three weeks in January 2026 during the even semester, each session began with a pretest and ended with a posttest for both groups. The three-weeks course consisted of 3x5 hours of instruction focused on chemical equilibrium, and the learning process was conducted intensively to ensure that learning objectives were achieved despite the limited timeframe. The experimental group received instruction via PBL-based e-modules and the control group was taught using the school conventional materials. A scoring rubric was used to assess students' scientific literacy skills. For multiple-choice items, a score of 1 was assigned for each correct answer and 0 for each incorrect answer, while essay items were scored using a rubric with a score range of 0-4.

To reduce the impact of external variables, the same instructor taught both groups, with equal lesson durations and identical time allocations. Teaching aids and lesson plans were standardized for all groups, and classroom conditions as well as the learning environment were carefully managed to prevent any treatment bias [21].

Data analysis involved calculating the N-gain, normality using the Liliefors test, homogeneity using the F-test, and hypothesis testing using an independent sample t-test. The Liliefors test was employed to determine whether the data followed a normal distribution, while the F-test evaluated the homogeneity of variances. If the data met the criteria for normality and homogeneity, a t-test was performed (parametric statistical tests were applied) [22].

RESULT AND DISCUSSION

4.1 Research Result

4.1.1 Results of the Science Literacy Assessment

Analysis of students' scientific literacy in the pretest revealed that the majority of both the experimental and control groups exhibited low skill levels, particularly in the categories of scientific illiteracy and nominal scientific literacy, while the categories of functional and conceptual scientific literacy remained relatively low. After the intervention, posttest results for both groups showed an improvement in science literacy, indicated by a decrease in the percentage of students in the low scientific literacy category and an increase in those classified in the functional and conceptual scientific literacy categories. Tables 4 and 5 present the analysis of the experimental class's science literacy levels from the data obtained in the pretest and posttest outcomes.

TABLE 4. Results of the Analysis of the Pre-test Science Literacy Levels in the Experimental Class

No	Literacy Level	Percentage of Science Literacy Questions by Question Number (%)									Avarage
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
1	Scientific Illiteracy	74%	59%	89%	93%	30%	74%	89%	59%	67%	70%
2	Nominal Scientific Literacy	22%	41%	7%	7%	30%	15%	7%	30%	19%	20%
3	Functional Scientific Literacy	4%	0%	4%	0%	37%	7%	4%	7%	11%	8%
4	Conseptual Scientific Literacy	0%	0%	0%	0%	4%	4%	0%	4%	4%	2%

TABLE 5. Results of the Analysis of the Post-test Science Literacy Levels in the Experimental Class

No	Literacy Level	Percentage of Science Literacy Questions by Question Number (%)									Avarage
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
1	Scientific Illiteracy	4%	4%	26%	19%	0%	0%	44%	15%	11%	14%
2	Nominal Scientific Literacy	33%	37%	26%	22%	11%	15%	0%	26%	26%	22%
3	Functional Scientific Literacy	41%	33%	30%	30%	37%	22%	33%	22%	19%	30%
4	Conseptual Scientific Literacy	22%	26%	19%	30%	52%	63%	22%	37%	44%	35%

Next, the pretest and posttest results of science literacy for the control class are presented in Table 6 and 7.

TABLE 6. Results of the Analysis of the Pre-test Science Literacy Levels in the Control Class

No	Literacy Level	Percentage of Science Literacy Questions by Question Number (%)									Avarage
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
1	Scientific Illiteracy	70%	70%	81%	89%	22%	56%	85%	59%	78%	68%
2	Nominal Scientific Literacy	30%	19%	19%	11%	74%	37%	11%	26%	19%	27%
3	Functional Scientific Literacy	0%	11%	0%	0%	0%	7%	4%	11%	4%	4%
4	Conseptual Scientific Literacy	0%	0%	0%	0%	4%	0%	0%	4%	0%	1%

TABLE 7. Results of the Analysis of the Post-test Science Literacy Levels in the Control Class

No	Literacy Level	Percentage of Science Literacy Questions by Question Number (%)									Avarage
		1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	
1	Scientific Illiteracy	22%	22%	19%	22%	11%	15%	37%	22%	19%	21%
2	Nominal Scientific Literacy	30%	30%	37%	15%	37%	26%	41%	30%	19%	29%
3	Functional Scientific Literacy	26%	37%	26%	33%	30%	26%	4%	22%	26%	26%
4	Conseptual Scientific Literacy	22%	11%	19%	30%	22%	33%	19%	26%	37%	24%

4.1.2 Result of Science Literacy Skills

Students' science literacy skills were evaluated using the N-gain, which was calculated from pretest and posttest scores. The experimental group outperformed the control group in terms of N-gain, with detailed data as presented in Table 8.

TABLE 8. N-Gain Test Results of Science Literacy

Literacy Type	Class	N	Pretest	Posttest	N-Gain	Category
Science	Control	27	21	56	0.45	Medium
	Experiment	27	20	64	0.55	Medium

4.1.2 Hypothesis Test

The two sample groups were compared through statistical analyses, including assessments of normality, homogenity, and hypothesis testing. Results from the normality test using Liliefors are presented in Table 9.

TABLE 9. Normality Test Results of Science Literacy

Literacy Type	Normality Test				Decision
	Eksperiment		Control		
	L_o	L_{table}	L_o	L_{table}	
Sains	0.156	0.173	0.162	0.173	Normal

Next, a homogeneity test was performed for both sample groups, and the results are shown in Table 10.

TABLE 10. Numerasi Homogeneity Test Results of Science Literacy

Literacy Type	Homogeneity Test		Decision
	F_{count}	F_{table}	
Science	0.9185226	1.9292127	Homogeneous Data

Hypothesis testing was subsequently performed for both sample groups, with the results displayed in Table 11.

TABLE 11. Hypothesis Test Results of Science Literacy

Literacy Type	Hypothesis Test		Decision
	t_{count}	t_{table}	
Science	2.3781	1.6747	H_o is rejected; H_1 is accepted

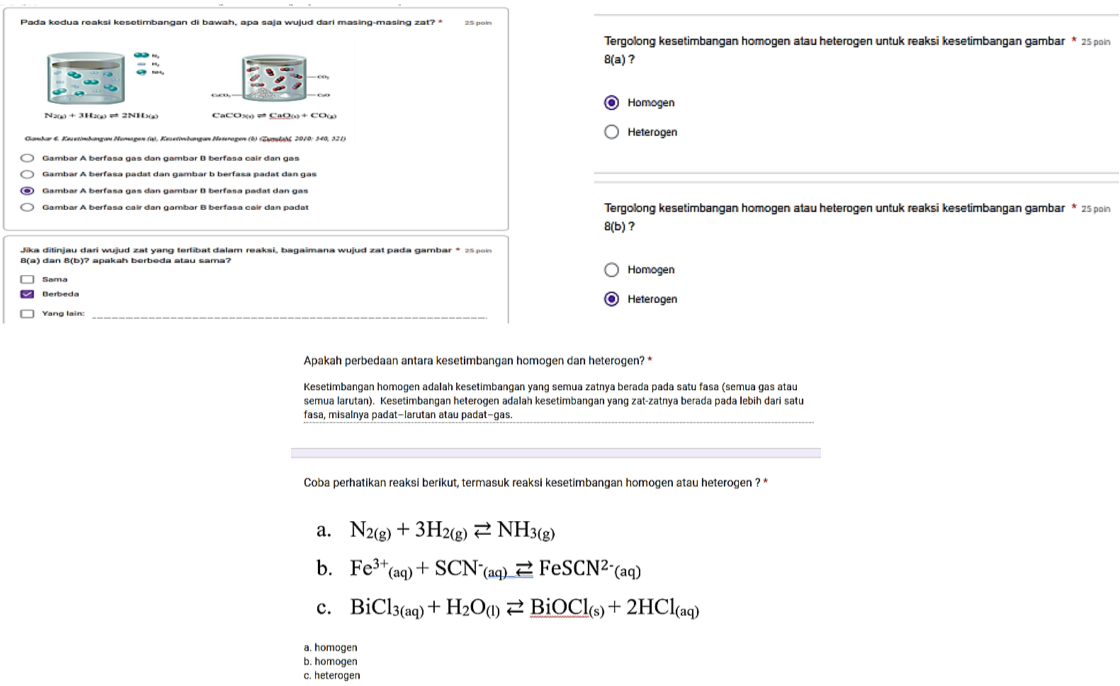

FIGURE 2. Example of Students' Answers to the E-Module

Students' science literacy skills are reflected in their achievement of learning objectives. For example, the objective of explaining the concept of chemical equilibrium is demonstrated by their ability to answer questions in the e-module, particularly in the subsections on homogeneous and heterogeneous equilibrium, as shown in Figure 2 (Example of Students' Answers to the E-Module).

4.2 Discussion

The N-gain analysis (Table 8) indicates a clear difference in scientific literacy between the experimental and control groups. The experimental group obtained an N-gain of 0.5, while the control group scored 0.45. Although both scores are categorized as "moderate," the higher N-gain in the experimental group suggests that the PBL-based electronic module is more effective in enhancing science literacy. To strengthen this claim the magnitude of the effect was also examined using effect size analysis. Based on the mean difference between groups, the calculated Cohen's d value of 0.65 indicates a moderate effect, suggesting that the intervention has a meaningful practical impact beyond statistical significance, the These results demonstrate that implementing a PBL-based e-module on chemical equilibrium concepts is appropriate for supporting learning and can effectively improve both scientific literacy skills.

From the results obtained of the pretest and posttest analysis of scientific literacy, a more pronounced improvement was observed in the experimental class. Initially, most students in both classes were categorized as scientific literacy. However, after instruction students' in the experimental class showed a clear shift from lower to higher levels of scientific literacy. The proportion of students at the initial literacy level decreased markedly, accompanied by a substantial increase in students achieving functional and conceptual literacy. Although a similar trend was observed in the control class, the progression was less pronounced. This pattern suggests that the intervention not only improved overall performance but also facilitated a meaningful transition toward. This shift indicates not only quantitative improvement but also qualitative progression in literacy levels, suggesting that students moved toward higher-order thinking competencies. From these results, it can be concluded that teaching in the experimental class was more effective in improving student's scientific literacy, enabling them not only to acquire knowledge but also to develop a deeper understanding of the concepts. This finding can be interpreted through the lens of Problem-Based Learning (PBL) theory, which emphasizes active knowledge construction, contextual problem solving, and student-centered inquire. These elements are known to support the development of scientific literacy competencies such as explaining phenomena, evaluating evidence, and interpreting data.

The normality test results presented in Table 9 show an L-table value of 0.173 for science literacy. The calculated L_o values were 0.156 for the experimental group and 0.162 for the control group, both evaluated at a 95% confidence level. Since all L_o values in both groups were lower than the L_{table} value ($L_o < L_{table}$), Therefore, It can be concluded that the data for both groups follow a normal distribution.

The results of the homogeneity of variances test are presented in Table 10, which shows an F_{table} value of 1.9292 for science literacy and an F_{count} value of 0.9185. Since the F_{count} value is less than the F_{table} value, This suggests that the variances of the two groups are homogeneous. Based on these results, it can be concluded that both groups have equal variances, thereby meeting the assumption of homogeneity. With this assumption met, further statistical analysis can proceed using parametric tests, such as the t-test, since the assumption of homogeneity of variances has been satisfied.

Next, a hypothesis test was implemented to evaluate whether the experimental group differed significantly from the control group. Since assumptions of normality and homogeneity of variance were fulfilled by the data, a t_{test} was employed. As shown in Table 11, the computed t_{count} value is 2.3781, compared to the critical t_{table} value of 1.6747 at a 95% confidence level. Since the calculated t_{count} value exceeds the critical t_{table} value, the analysis led to the rejection of H_0 and acceptance of H_1, revealing that student using the PBL-based chemistry equilibrium e-module had significantly higher science literacy skills than those who did not. However, beyond statistical significance, this result should be interpreted in terms of how the learning process facilitated by PBL contributes to literacy development, rather than relying solely on numerical differences.

This e-module includes lesson content, learning activities, worksheets, and self-assessments. For example, as shown in Figure 2, this e-module includes questions that promote the development of science literacy. This finding is also consistent with the design of the e-module, as the syntactic elements embedded within it correspond with scientific literacy frameworks by fostering students' abilities to interpret, analyze, and apply scientific concept, as depicted in Figure 3. Furthermore, the e-module aligns with PBL syntax problem orientation, investigation, and reflection which supports meaningful and active learning processes. This approach facilitates the development of science literacy by enganging students in contextual problem solving, encouraging evidence-based reasoning, and promoting deeper conceptual understanding.

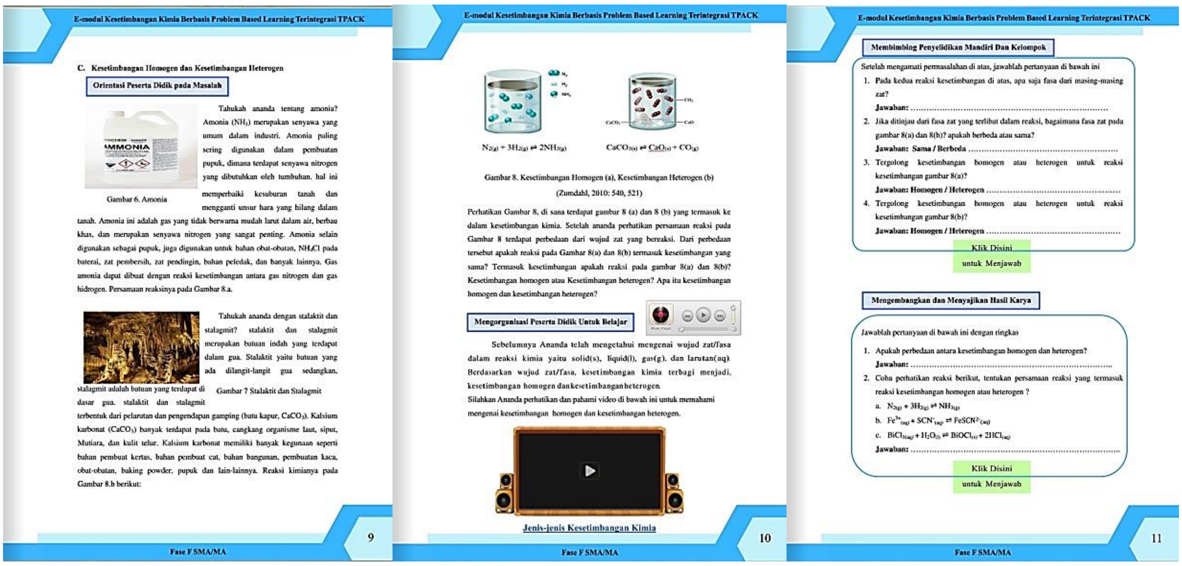

FIGURE 3. Demonstration of Syntax in Science Literacy E-Modules

In the three images shown Figure 3, students are encouraged to respond to questions by observing the images and following the information-processing steps provided in the e-module. The questions are intended to facilitate students' comprehension of chemical equilibrium concepts, particularly the distinction between homogeneous and heterogeneous equilibrium. In the initial section, students are asked to determine the phase of each substance (solid, liquid, gas, or solution) involved in the two equilibrium reactions shown. This is intended to help students recognize the characteristics of each substance in the reaction. Next, in the following questions, students are prompted to compare the states of the substances in the two images, enabling them to identify similarities or differences between the reactions in terms of phase. These tasks require students to analyze relationship between representations, which is a key component of scientific literacy

In the next question, students are instructed to classify types of equilibrium based on the phase of the substances involved, namely homogeneous equilibrium (all substances in the same phase) or heterogeneous equilibrium (consisting of more than one phase) [23]. Thus, students are gradually guided to develop a conceptual understanding of the classification of chemical equilibrium. Additionally, in the section on developing and presenting work, there is a literacy question asking students to explain the difference between homogeneous and heterogeneous equilibria and to categorize several chemical reactions into these two types of equilibrium. This activity supports the development of conceptual understanding and classification skills, which are essential components of higher-level scientific literacy. Overall, The sequence of questions in this e-module both assesses conceptual understanding and cultivates critical thinking skills as well as the aptitude to interpret visual information, and the capacity to connect theoretical concepts with real-world examples of chemical reactions.

The learning activities in the e-module are supplemented with images, videos, audio, and animations covering macroscopic, microscopic, and symbolic aspects [24]. For example, in the stage of organizing students for learning, an image illustrating the concept of dynamic equilibrium is presented, as shown in Figure 4. The integration of multiple representations is known to support deeper conceptual understanding in chemistry, thereby strengthening scientific literacy development.

Figure 4 illustrates the macroscopic, microscopic, and symbolic aspects of the concept of dynamic equilibrium. As shown in the figure, the initial state consists of a container filled with colored N_2O_4 molecules and a small amount of NO_2 at a low temperature. The container is then heated; after some time, the N_2O_4 begins to decompose into NO_2, which gradually turns yellow. After some time, the concentration of N_2O_4 decreases, which slows the formation of NO_2 and causes the container to turn brown. Simultaneously, the concentration of N_2O_4 rises as the reaction producing N_2O_4 takes place. At this point, the rate of N_2O_4 formation equals the rate of NO_2 formation. At this point, dynamic equilibrium is said to be achieved [25]. The microscopic aspects in this e-module can guide students in understanding the concept of dynamic equilibrium and improve their scientific literacy.

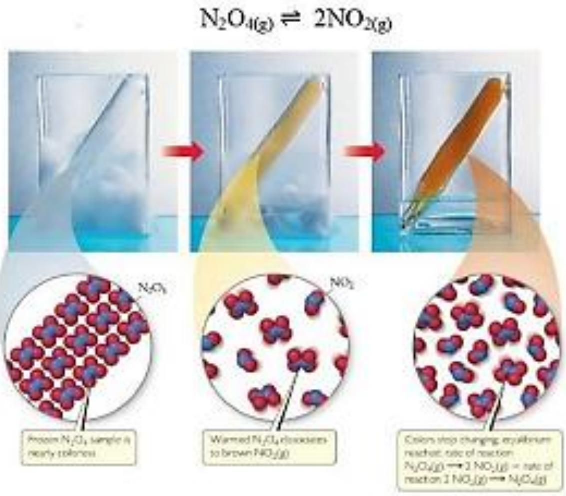

FIGURE 4. Dynamic equilibrium in the elastic modulus

This e-module presents a problem at the beginning of the learning process a problem to be solved through investigation, data presentation, and analysis of the investigation results. Based on the observations made during this activity, students are guided to solve the problem presented in the e-module, thereby broadening their horizons and encouraging them to seek out more information. Problem-Based Learning (PBL) helps students develop investigative and problem-solving abilities. Implementing this model also has the benefit of strengthening the process of conceptual understanding. This is because the PBL model requires critical thinking skills and actively involves students in solving problems [26]. Consequently, students benefit from chemistry learning as they can solve problems related to daily life, as supported by previous studies.

These findings are consistent with previous and international studies indicating that PBL enhances scientific literacy and higher-order thinking skills by promoting active engagement and inquiry-based learning. Research by Ardiansyah & Yerimadesi [11] indicates that the PBL-based e-module on chemical equilibrium is both valid, with a score of 0.905, and practical, as reflected by 95% of teachers and 88% of students. Karmila et al [27] also found an increase in science and numeracy literacy (86.66%) as well as high feasibility based on expert validation. Additionally, Hidayanti et al [28] found that PBL-based e-modules are more effective than conventional instruction in improving students' science literacy. Furthermore, Yerimadesi et al [17] demonstrated that implementing the Problem-Based Learning (PBL) model significantly enhances students' chemical numeracy skills, producing a greater effect than gender differences, as evidenced by higher N-gain scores in the experimental group compared to the control group. These findings are further strengthened by a systematic literature review conducted by Shiddiqi et al [29] which reported that the application of PBL in chemistry education consistently improve students' conceptual understanding critical thinking skills, and active engagement in the learning process.

This study also shows an increase in science literacy skills after using a PBL-based e-module on chemical equilibrium, although the improvement is still within the moderate range. This indicates that while PBL contributes positively, the mechanism of impact has not been fully optimized. Even though the e-module was designed around a problem-based approach, the questions presented within it are not yet fully open-ended. This situation limits students' scope for exploration in expressing opinions, engaging in deep reasoning, and developing scientific arguments. Consequently, the expected improvement in science literacy has not yet been optimally achieved. These results suggest that using the PBL-based chemistry equilibrium e-module has positively contributed to the enhancement of students' science literacy; however, further development is still needed, particularly in the design of more open-ended and challenging questions. For example, by presenting contextual problem-based questions that encourage analysis, evaluation, and reflection, so that students can construct knowledge more deeply. Thus, an e-module design that is not only problem-based but also equipped with open-ended questions becomes essential to more effectively, fairly, and sustainably support the development of students' science literacy.

CONCLUSION

The results of the research show that students who received instruction using a PBL-based e-module on chemical equilibrium demonstrated significantly higher science literacy skills compared to students who were not provided with the e-module. Consequently, integrating this e-module showed positively impacted the science literacy of grade F students at SMAN 9 Padang. This improvement was confirmed quantitatively via N-gain analysis and hypothesis testing, where the experimental group achieved higher results than the control group. Notably, students' science literacy showed particular improvement in areas such as conceptual understanding, data analysis, and the interpretation of graphs and chemical symbols. Additionally, students began demonstrating the ability to draw conclusions and relate concepts to real-life contexts. However, the improvement in science literacy achieved is still considered moderate. This is likely influenced by the fact that the questions in the e-module are not yet fully open-ended, so students' abilities to develop scientific reasoning, critical thinking, and construct arguments have not yet developed optimally. Therefore, it is suggested that further research be carried out by developing e-modules equipped with open-ended questions and more diverse contexts, so that the effectiveness of learning in improving science literacy can be optimized.

Authors'contribution

- ***Conceptualization***: *Nikmatusyadiah*
- ***Data curation***: *Nikmatusyadiah*
- ***Formal Analysis***: *Nikmatusyadiah*
- ***Funding acquisition***: *Nikmatusyadiah*
- ***Investigation***: *Nikmatusyadiah*
- ***Methodology***: *Nikmatusyadiah*
- ***Project administration***: *Nikmatusyadiah*
- ***Resources***: *Nikmatusyadiah*
- ***Software***: *[Nikmatusyadiah];*
- ***Supervision***: *Yerimadesi*
- ***Validation***: *Yerimadesi*
- ***Visualization***: *Nikmatusyadiah*
- ***Writing – original draft***: *Nikmatusyadiah*
- ***Writing – review & editing***: *Nikmatusyadiah, Yerimadesi*

All authors have read and agreed to the published version of the manuscript.

Ethics Statement

This research involved human subjects who had given informed consent to participate. All participants received treatment in accordance with their rights, dignity, and applicable research ethics principles.

Data availability statement

The data will be available upon request.

Funding

This research received no external funding

Acknowledgments

The authors also thank the principal, teachers, and students of SMA Negeri 9 for their cooperation and assistance during the research process. During the preparation of this manuscript, the authors used Microsoft Excel for data processing and Microsoft Word for manuscript preparation.

Conflicts of Interest

The authors declare no conflicts of interest.

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