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IMPROVING STUDENTS' CHEMICAL LITERACY SKILLS THROUGH PROBLEM-BASED LEARNING MODELS ON STOICHIOMETRY TOPICS

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Abstract

The purpose of this study was to determine students' chemical literacy skills after being taught stoichiometry using a problem-based learning model. The Research design is a pre-experimental design with a one-group pretest-posttest design. The sample in this study was 13 new students of Chemical Engineering at PGRI Madiun University in the 2025/2026 academic year. Data collection used a context-based chemical literacy test carried out before and after PBL learning. Based on the Research, the pretest results showed that 100% of students had low chemical literacy, while the posttest results showed that 74% had low chemical literacy and 16% had moderate chemical literacy. Then, the analysis of students' chemical literacy levels from their pretest answers showed the highest percentage at the Scientific Illiteracy Level (72%) and the posttest results showed the most significant percentage at the Functional Scientific Literacy Level (32%). The implementation of PBL to improve students' chemical literacy skills should consider several factors, such as the lecturer's support for learning, the selection of material topics, information on students' misconceptions in stoichiometry, and alignment between the activity design and targeted literacy indicators.
Keywords: stoichiometry, chemical literacy, problem based learning

INTRODUCTION

Chemistry learning develops 21st-century skills [1]. The World Economic Forum identifies scientific literacy, including chemical literacy, as one of 16 essential 21st-century skills. Students with this skill gain conceptual knowledge, critical thinking, and problem-solving skills, and can apply them in real situations, all of which benefit them after graduation. At the university level, chemical literacy encompasses mastery of concepts, their application in life or industry, and higher-order cognitive skills such as scientific analysis and argumentation [2].

However, based on interviews with Chemical Engineering students, it is evident that students have a better grasp of calculation formulas, such as those in stoichiometry. However, this mastery is not accompanied by a deep understanding of context, nor by the ability to solve real problems in the engineering field. This condition makes students' chemical literacy in the contextual aspect and scientific argumentation competency relatively weak, so a more contextual and inquiry-based learning approach is needed. Learning by linking basic chemistry teaching materials with real-world problems can also support critical thinking skills and improve student literacy [3]. One learning model that can be applied to improve students' chemical literacy knowledge is the problem-based learning (PBL) model.

PBL is a learning model that aims to build students' conceptual understanding through problems that occur in daily life. PBL has advantages including (1) having an effective learning design to teach real systems and applications in chemistry [3], (2) can improve high-level thinking skills, learning independence and student motivation [4], (3) can be applied at various levels (undergraduate and graduate), both face-to-face and online, increasing student involvement and ability to connect chemical concepts with environmental issues which is an important factor in improving chemical literacy [5].

The success of implementing PBL to improve students' literacy skills is influenced by several factors, including the suitability of the learning design to classroom implementation, student readiness, and the quality of the problems discussed [6]. Sjöström [7] also emphasized that chemical literacy includes understanding the socio-scientific context, interpreting data, and engaging in evidence-based argumentation. If PBL activities are not clearly focused on these aspects, literacy skills will not be improved. In addition, lecturer guidance in learning, tiered problem design, and clear formative assessment are essential for PBL to produce significant results [5].

The purpose of this study was to determine the chemical literacy skills of Chemical Engineering students in stoichiometry after using the PBL model. Stoichiometry was chosen for this study because it is a fundamental yet conceptually complex topic in chemistry that combines quantitative calculations with an understanding of reactions, making it highly relevant for assessing students' chemical literacy, not just their ability to solve mathematical problems [8]. Furthermore, stoichiometry is a challenging topic and requires more than just calculations. It also needs to be connected to a meaningful context to enhance students' thinking skills. Therefore, approaches such as PBL based on socio-scientific issues are required to foster critical thinking and deepen understanding of concepts [9].

This research is highly relevant to the development of learning processes in higher education. The results are expected to contribute to lecturers and higher education institutions, as well as to the development of more innovative and effective learning strategies to improve students' chemical literacy across other courses.

METHOD

This study employed a quantitative pre-experimental design with a one-group pretest-posttest. The sample consisted of 13 new Chemical Engineering students at Universitas PGRI Madiun in the 2025/2026 academic year. This study was applied to basic chemistry courses, specifically the stoichiometry topic, focusing on the concept of moles given its relevance to daily life. The problem used in this PBL learning model refers to the issues faced by the Environmental Office, particularly those related to waste. The implementation of the PBL model aligns with the learning syntax according to Arends [10], which consists of five phases: Orienting students to the problem, in this case, regarding environmental issues; organizing students; guiding individual/group investigations; developing and presenting work; and analyzing and evaluating the problem-solving process. The initial level of students' chemical literacy was identified through a pretest. At the end of the learning activity, students' chemical literacy was assessed again with a posttest.

The chemical literacy test skills used are an essay question consisting of 12 questions, arranged according to the chemical literacy indicators of Schwartz et al. [11]. Moreover, has been validated by two expert lecturers from Universitas Bojonegoro and Universitas PGRI Madiun. The chemical literacy test essay questions on stoichiometry have met the criteria for content validity, construct validity, and language validity, and have obtained a reliable value of 0.761. The chemical literacy test used during the pretest and posttest was identical, specifically regarding the concept of moles.

According to Shwartz, chemical literacy indicators include knowledge of chemical matter, chemistry in context, and high-level learning skills [12]. The chemical literacy assessment system uses five levels of chemical literacy: scientific illiteracy, nominal scientific literacy, functional scientific literacy, conceptual scientific literacy, and multidimensional scientific literacy [13]. Scientific Illiteracy (SI) is defined as a level where a person cannot provide an answer or the answer is incorrect. Nominal Scientific Literacy (NSL) is defined as a level where a person can only give a concept name but cannot explain the concept meaningfully. Functional Scientific Literacy (FSL)

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is defined as a level at which a person can explain an idea, but their understanding remains limited. Conceptual Scientific Literacy (CSL) is the ability to explain concepts clearly and establish relationships among them. Multidimensional Scientific Literacy (MSL) is defined as a level at which a person can not only explain concepts and their relationships, but also connect scientific concepts to everyday life problems, such as the interrelationships among science, technology, and social developments.

The data analysis technique used was descriptive statistics. The pretest and posttest scores for students' chemical literacy skills were scored according to the criteria listed in Table 1. A score of 4 was the maximum for each question, so the test's maximum raw score was 48. Then, chemical literacy skills were categorized according to the categories in Table 2.

Table 1. Scoring of Chemical Literacy Test Answers

Scientific Literacy Level	Score
Scientific Illiteracy (SI)	0
Nominal Scientific Literacy (NSL)	1
Functional Scientific Literacy (FSL)	2
Conceptual Scientific Literacy (CSL)	3
Multidimensional Scientific Literacy (MSL)	4

[14]

Table 2. Chemical Literacy Ability Category

Test Score	Ability Category
< 61	Low
61 – 84	Medium
> 84	High

[15]

RESULTS AND DISCUSSION

This study aims to determine the chemical literacy of new Chemical Engineering students in stoichiometry after applying the PBL model. The problem raised in the stoichiometric analysis is to address waste issues, particularly in the Ponorogo area. The Ponorogo Regency Government is seeking chemical-based scientific solutions to address the increasing volume of waste at several critical locations, particularly the Mrican Landfill, Ngebel Lake, the city center, traditional markets, and school environments. Students were divided into five groups to discuss five case studies: Case 1: Methane Gas from the Mrican Landfill, Case 2: Plastic Waste Incineration at Ngebel Lake, Case 3: Electronic Waste from a Cell Phone Repair Shop in Ponorogo City, Case 4: Organic Waste Processing at Songgolangit Market, and Case 5: Paper Recycling from Schools and Offices.

In this study, PBL was systematically implemented across four meetings. The relationship between PBL Syntax and Chemical Literacy Indicators can be seen in Table 3. This arrangement was made so that each learning stage, starting from Orienting Students to the Problem, Organizing Students for Learning, Guiding Individuals or Groups, Developing and Presenting Groups, and Analyzing and Evaluating the Problem-Solving Process, could take place clearly and thoroughly. This implementation pattern aligns with previous Research, which found that PBL should be implemented over several meetings to actively engage students in the problem-solving process and build a deeper understanding of the concept, rather than in a single meeting [5]. Data on students' chemical literacy skills were collected before and after PBL implementation, and the results are presented in Table 4. The pretest results showed that 100% of students were in the low chemical literacy category. This result indicates that although students had studied stoichiometry at a previous level, they had not necessarily mastered the material. Students still did not understand the meaning of the mole concept and continued to have difficulty connecting it to mass and volume in real-world problems. Based on the posttest results, there were a decrease in the low category and an increase in the middle categories.

The results of this study indicate that implementing Problem-Based Learning (PBL) has not optimally improved students' chemical literacy skills, given their known low levels. This finding aligns with various studies that indicate the effectiveness of PBL is highly dependent on the quality of its design and implementation. Overton & Randles [16] emphasized that PBL will not have a significant impact if the problems given are too complex or lack adequate learning support. Lecturers can provide support in the form of instructions, examples, guiding questions, modeling, or breaking down tasks at the start. Stoichiometry material is characterized by material with a high level of element interactivity, so that new Chemical Engineering students tend to experience excessive cognitive load. Leppink [17] and Paas et al. [18] explained that complex tasks without learning support can increase extraneous cognitive load, making it difficult for students to integrate the concept of moles in mathematical calculations in the problems presented.

Table 3. The Relationship between PBL Syntax and Chemical Literacy Indicators

Syntax of Problem-Based Learning	Chemical Literacy Indicator	Activity
Student Orientation on the Problem	Chemistry in Context	Discussing learning objectives and phenomena in the environment, explaining learning logistics needs, and motivating students
Organize students to learn	Knowledge of science and chemical content	Students define and organize investigations to solve problems.
Guiding individual or group	Knowledge of science and chemical content HOLS (High Order Learning Skills)	Students seek accurate information, conduct investigations, and seek explanations for solutions.
Develop and present the group	Knowledge of science and chemical content HOLS (High Order Learning Skills)	Students plan appropriate and relevant products to deliver results.
Analyze and evaluate the probelm solving process	Knowledge of science and chemical content	Students reflect on the investigations and processes that have been carried out.

Table 4. Categories and Percentage of Student Chemical Literacy

Category	Test Score	Pretest		Postest	
		Number of Students	Percentage	Number of Students	Persentase (%)
Low	< 61	13	100	11	74
Medium	61 – 84	0	0	2	16
High	> 84	0	0	0	0

Stoichiometry is known to lead to misconceptions among students frequently. According to Suparman et al. [19], misconceptions that go unaddressed can hinder the development of chemical literacy, even in innovative learning models. Other Research also shows that students need structured examples to understand problem-solving patterns, such as worked examples, which play a crucial role in establishing initial schemas before engaging in higher-level problem-solving, such as PBL [20]. In addition to instructional design factors, the low improvement in chemical literacy in this study was likely influenced by the characteristics of the participants: early-semester Chemical Engineering students who generally lack readiness for self-directed learning. Various studies have shown that PBL's effectiveness is highly dependent on students' independent learning ability. Millanzi et al. [21] found that students with low Self-directed Learning Readiness (SDLR) require intensive guidance to utilize PBL optimally; without such support, students tend to be confused about managing information and determining learning strategies. Similar findings were reported by Sadeghi et al. [22], who stated that first-year students have weaknesses in time management, learning planning, and academic initiative, which prevent the implementation of problem-based learning models in accordance with the lesson plan. The low SDLR among new students is a real and significant factor that may explain why PBL did not optimally improve chemical literacy in this study. Furthermore, when examining students' responses to the questions, the percentage of students at each chemical literacy level before and after PBL learning is shown in Figure 1.

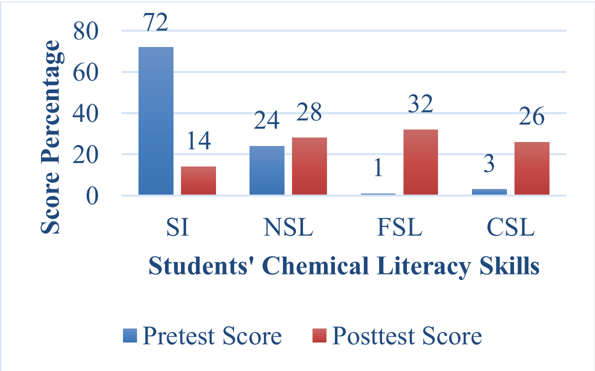

Figure 1. Pretest and Posttest Score of Students' Chemical Literacy Skills

Based on the pretest results, the most significant percentage of student answers was at the SI level (72%), and, from the posttest results, the most significant percentage of student answers was at the FSL level (32%). The quality of student answers improved after PBL implementation, but remained in the low category. After PBL learning, most students were able to explain the concept, but their understanding remained limited. One example of a student's answer in case 1, converting organic waste into biogas at the FSL level, is shown in Figure 2. In the question, a discourse was given on the use of organic waste to produce biogas, then a HOLS question was given on the number of moles of methane gas produced from fermentation, and students were asked to evaluate whether the volume of biogas was sufficient to light the stove for a specified time. It can be seen from one student's answer that there were calculation steps and decision-making in the given question, but the explanation of assumptions and operational efficiency remained limited.

In the same question, the student's answer at the SI level is shown in Figure 3. The student did not show the calculation of CH_4 moles, did not use the STP concept, did not perform an energy calculation, and the answer was only the student's own opinion. Then, the example answer at the NSL level in Figure 4 shows that students can already mention the relationship between the combustion of CH_4 gas and the production of energy. However, no calculations of moles or energy are provided, and conclusions are drawn without a quantitative basis. Furthermore, student answers at the CSL level are shown in Figure 5. The difference between student answers at the CSL level and the level below FSL lies in the mention of ideal assumptions and cause-and-effect relationships, such as the assumption that all energy can be appropriately utilized to operate the stove. Students provide assumptions about the optimal time for combustion given the available energy if the conditions for methane combustion are perfectly met. The results of the student's answers do not show any MSL level.

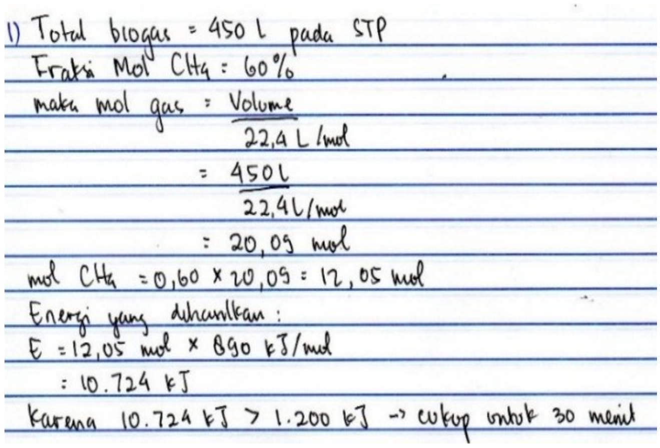

Figure 2. Example of Student Answers at the FSL Level

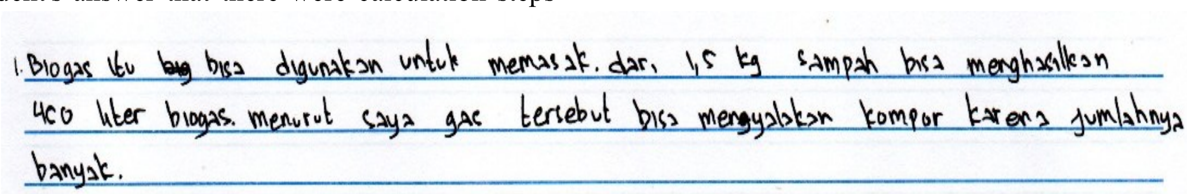

Figure 3. Example of Student Answers at the SI Level

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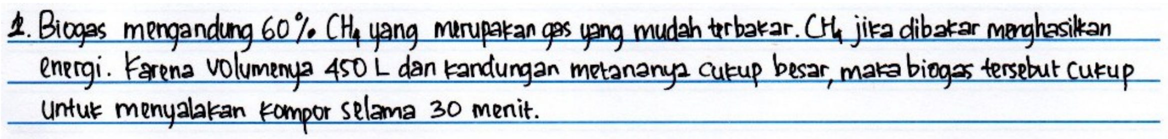
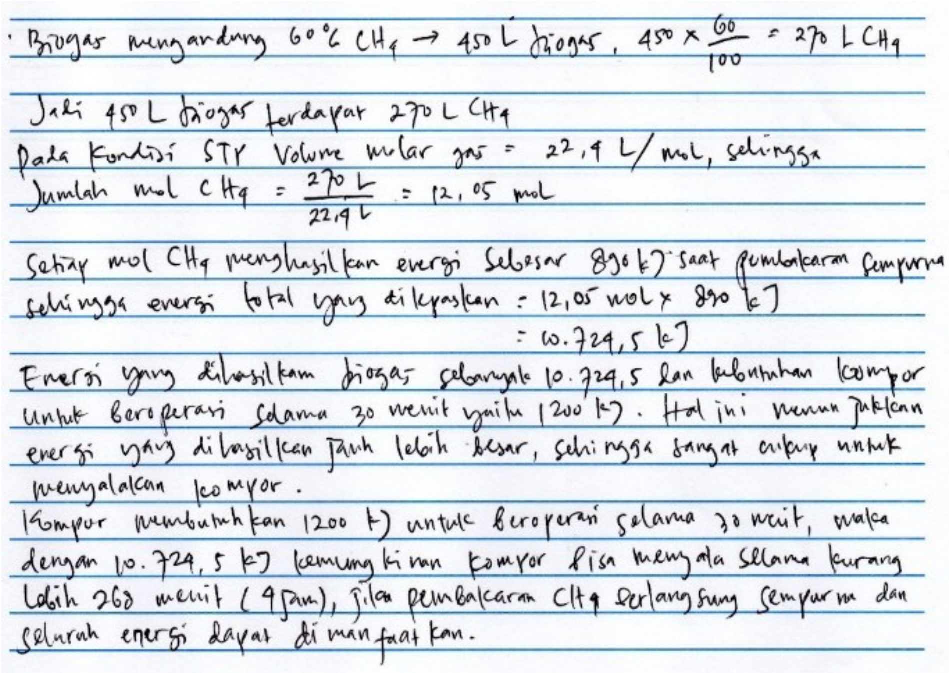


1. Biogas mengandung 60% CH_4 yang merupakan gas yang mudah terbakar. CH_4 jika dibakar menghasilkan energi. Karena volumenya 450 L dan kandungan metananya cukup besar, maka biogas tersebut cukup untuk menyalakan kompor selama 30 menit.

Figure 4. Example of Student Answers at the NSL Level



Biogas mengandung 60% CH_4 → 450 L biogas, $450 \times \frac{60}{100} = 270$ L CH_4

Jadi 450 L biogas terdapat 270 L CH_4

Pada kondisi STP volume molar gas = 22,4 L/mol, sehingga

Jumlah mol CH_4 = $\frac{270 \text{ L}}{22,4 \text{ L}}$ = 12,05 mol

Setiap mol CH_4 menghasilkan energi sebesar 890 kJ saat pembakaran sempurna

sehingga energi total yang dilepaskan = 12,05 mol × 890 kJ

= 10.724,5 kJ

Energi yang dihasilkan biogas sebanyak 10.724,5 dan kebutuhan kompor untuk beroperasi selama 30 menit yaitu 1200 kJ. Hal ini menunjukkan energi yang dihasilkan jauh lebih besar, sehingga sangat cukup untuk menyalakan kompor.

Kompor membutuhkan 1200 kJ untuk beroperasi selama 30 menit, maka dengan 10.724,5 kJ kemungkinan kompor bisa menyala selama kurang lebih 268 menit (4 jam), jika pembakaran CH_4 berlangsung sempurna dan seluruh energi dapat dimanfaatkan.

Figure 5. Example of Student Answers at the CSL Level

Thus, it can be seen that efforts to improve chemical literacy skills by implementing PBL learning need to pay attention to a combination of intensive lecturer guidance in learning, especially when applied to new students, selection of material topics, initial knowledge related to student misconceptions so that things that need to be addressed first can be identified, as well as the accuracy between activity design and targeted literacy indicators.

CONCLUSION

This study aimed to determine students' chemical literacy skills after implementing a problem-based learning (PBL) model for stoichiometry. Based on pretest results, all students (100%) were in the low chemical literacy category. This finding indicates that, before PBL was implemented, students were unable to connect stoichiometry concepts to the context of scientific problems adequately. After implementing problem-based learning, students' chemical literacy skills improved. Posttest results showed that the percentage of students in the low chemical literacy category decreased to 74%, while 16% reached the moderate chemical literacy category. Although this improvement was not uniform across all categories, the results indicate that PBL learning has a positive impact on students' chemical literacy development.

Further analysis of chemical literacy levels revealed a significant shift. In the pretest, students' literacy levels were dominated by Scientific Illiteracy (72%), followed by Nominal Scientific Literacy (24%), with tiny percentages at the Functional Scientific Literacy (1%) and Conceptual Scientific Literacy (3%), and no students at the Multidimensional Scientific Literacy level. After PBL learning, the percentage of Scientific Illiteracy decreased significantly to 14%, while Functional Scientific Literacy increased to 32% and Nominal Scientific Literacy to 28%. These results indicate that PBL learning can encourage students to achieve a more functional literacy level in understanding and applying stoichiometry concepts.

Improving chemical literacy skills through PBL implementation requires support from several key factors, including the active role of lecturers in facilitating learning, the selection of contextually relevant topics, an understanding of students' initial misconceptions, and the alignment of learning activity design with targeted chemical literacy indicators. Furthermore, student readiness for independent learning, such as time management skills, learning planning, and academic initiative, is also a contributing factor to the success of PBL. By habituating problem-solving-oriented learning and strengthening chemical literacy on an ongoing basis, it is hoped that students' chemical literacy skills will continue to increase gradually.

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