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Enhancing Students' Chemical Literacy with Environmental Problem-Based Learning Models through Lesson Study Practices

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Abstract
The purpose of this study was to determine the increase in students' chemical literacy skills after being taught an environmental problem-based learning model through lesson study practices using quantitative descriptive analysis methods. This research flow uses the Lesson Study cycle stages consisting of Plan, Do, See, and Redesign. The subjects of this study were 17 first semester students of the Chemical Engineering and Physics Education Study Program at PGRI Madiun University who took basic chemistry courses. The data collected in this study were in the form of observation data and tests that measured students' chemical literacy skills. The results showed that students' chemical literacy skills were at a moderate level. In the Knowledge of Science and Chemical Content and Chemistry in Context aspects, the number of students who understood the concept increased, and the number of students who had misconceptions and did not understand the idea decreased. In the HOLS aspect, the most significant number of student answers were at the FSL level in terms of explaining the types of chemical bonds and depicting Lewis structures and in the explanation related to the possibility of compounds formed and the formation process of certain elements, the most significant number of student answers were at the NSL level. In the aspect of attitude, the learning outcomes show that most students' answers are at the NSL level. In this study, it can be seen that students' chemical literacy skills with problem-based learning have not been able to provide significant changes. Therefore, further steps are needed to improve the learning process that can support students' chemical literacy skills.

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INTRODUCTION

Chemistry as a branch of science is essential to study because by understanding chemistry, humans can understand the world around them and find solutions to problems in the environment. In addition, learning chemistry is also an effort to form a quality personality in accordance with the demands of the times. One of the keys for students to be able to adapt and solve existing problems in facing the era of technology in the 21st century is that students must have literacy skills, one of which is chemical literacy.

Chemical literacy is an understanding of the properties of material particles, chemical reactions, chemical laws and theories, and general chemical applications in everyday life (Imansari et al., 2018). Chemical literacy is essential for students so that they can understand chemical topics in depth and apply them in everyday life (Dewi et al, 2022). Chemical literacy is one part of scientific literacy and is the key to the chemistry learning process. Chemical literacy functions to select and sort out truth from scientific information obtained so that a conclusion can be drawn and communicated to the community. Chemical literacy skills can help students understand health, the environment, and problems faced in modern times that are highly dependent on the development of science, technology, and progress (Sari et al., 2022).

Improving literacy skills can be done by improving the quality of the learning process. According to (Rahayu, 2017), chemical literacy can be achieved if chemistry learning applies the following principles, namely (1) determining the chemical knowledge to be learned, (2) determining the relevant context in chemistry learning, (3) determining what learning skills will be developed in chemistry learning, and (4) emphasizing the affective aspect. Some learning that can improve chemical literacy includes context-based learning (Wiyarsi et al., 2020), ethnoscience-based learning (Sumarni, 2018), STEM project-based learning (Rahmawati et al., 2020), Problem-based learning (Paristiowati et al., 2019; Fareza et al., 2024) and STEM integrated Problem-Based Learning (Tairas et al., 2025). Paristiowati et al (2019) reported that problem-based learning is effective for learning for students who have low critical thinking skills. This means that the Problem-Based Learning model is suitable for use as a beginner learning model in training essential thinking skills essential thinking skills and improving students’ chemical literacy.

Based on the results of interviews with Chemical Engineering students at Universitas PGRI Madiun, it is known that students have only been taught using lecture methods and have never used learning models that can increase students’ interest in learning chemistry. Therefore, to overcome the above problems and to foster students’ chemical literacy skills, it is necessary to change the learning strategy, one of which is by implementing problem-based learning (PBL), which gives students space to explore their learning activities. Context-based learning, such as problem-based learning, will provide a more effective learning atmosphere and can improve students’ understanding, attitudes and motivation (Broman & Parchmann, 2014).

In this study, the chemical knowledge that will be used focuses on chemical bonding material. Chemical bonds are abstract and difficult-to-understand materials because students cannot see the real structure of atoms and how these atoms bond (Tsaparlis et al., 2018). Knowledge about chemical bonds can be provided by determining the relevant learning context, one of which is environmental pollution. Environmental pollution involves various elements, molecules and chemical compounds that are involved in chemical reactions, causing harmful impacts on the environment.

Many PBL studies in chemistry focus on improving content knowledge or conceptual understanding, especially in chemical bonding. Despite the known benefits of problem-based learning in chemistry education, there is limited understanding of how PBL approaches focused on chemical bonding contribute to the development of students' chemical literacy. Therefore, this study was conducted to determine the increase in students’ chemical literacy skills after being taught an environmental problem-based learning model through Lesson Study practices. Lesson Study practices are one form of collaborative teacher practice for developing professional skills in improving teaching and learning through professional joint practice (Mulyatun, 2017). This research is expected to contribute to the development of learning that can improve students’ chemical literacy, especially in chemical bonding material. Based on the study of literacy on compounds that cause chemical pollution and their effects on the environment, it is hoped that this will strengthen students’ chemical literacy skills.

METHOD

This study uses a quantitative descriptive analysis method. The flow of this research uses the stages of the Lesson Study cycle consisting of Plan, Do, See, and Redesign. In more detail, the research flow is presented in Table 1. The subjects of this study were 17 first-semester students of the Chemical Engineering and Physics Education study programs at Universitas PGRI Madiun. This research was carried out in the Lesson Study for Learning Community (LSLC) practice consisting of model lecturers, 8 observer lecturers and practitioners from Environental Office Ponorogo. The course chosen was the Basic Chemistry course with the material Ionic Bonding.

Table 1. Research flow

No.	Type of activity	Activity Description
1	Analysis of Learning Problems on Campus	Focus Discussion Groups are conducted for partner lecturers and practitioners to analyze learning problems on campus.
2	Interview with students who have taken basic chemistry courses	Students who had taken basic chemistry courses were interviewed to obtain information on the difficulties of studying basic chemistry material, especially chemical bonding material.
3	Problem Analysis in Industry (Environmental Office)	Chemical engineering lecturers and practitioners at the Environmental Service in Ponorogo analyse problems in the industry to determine what problems exist so that they can be used as learning materials for students in class.
4	*Plan*	Stages in the Plan 1. Analyze what environmental issues are related to ionic bonding material. 2. Determine environmental issues related to ionic bonding material. 3. Develop learning tools
5	*Do (Open Class-1)*	1. Pretest (Student Chemistry Literacy Test) 2. The lecturer conducts learning (open class) on the topic of ionic bonds using a problem-based learning model (PBL). 3. The observer observes student behaviour when learning is being carried out.
6	*See*	Team discussion to reflect on student learning findings
7	*Learning Redesign and Plan*	1. Make improvements to learning according to observer suggestions. 2. Develop appropriate learning tools for ionic bonding material.
8	*Do (Open Class-2)*	1. The lecturer conducts learning (open class) on the topic of covalent bonds using a problem-based learning model (PBL). The observer observes student behaviour while learning. 2. Posttest (Student Chemical Literacy Test)
9	*See*	Team discussion to reflect on student learning findings and lesson study data analysis

The data collected in this study were in the form of observation data and tests that measured students' chemical literacy skills. The chemical literacy test instrument for chemical bonding material, especially ionic bonding material, refers to the instrument developed by Wardani et al (2024) in the form of a two-tier choice diagnostic test to measure aspects of knowledge of science anda chemical content and chemistry in context with the level of understanding divided into understand, misconception, and less understand. Students who understand the idea give the correct answer and reason; students who experience misconception have the correct answer but the wrong reason or the wrong answer but the right reason; and students who do not understand the concept have the wrong answer and explanation. Meanwhile, to measure the HOLS and attitude aspects, an instrument was developed by Rizki & Yusmaita (2021) in the form of essay questions with a scoring system using literacy levels. The chemical literacy level consists of five levels, namely scientific illiteracy, nominal scientific literacy, functional scientific literacy, conceptual scientific literacy and multi-dimensioanl scientific literacy.

Table 2. Categories of Students' Chemical Literacy Abilities in Each Aspect

Aspects of Chemical Literacy	Sub-Indicators	Reference Source
Chemistry in context	Recognize the importance of chemical knowledge in explaining everyday phenomena.	(Wardani et al., 2024)
Knowledge of science and chemical content	Explaining the macroscopic level through the molecular structure of matter	
HOLS (High Order Learning Skills)	Understand and express the process of ionic bond formation.	(Rizki & Yusmaita, 2021)
	Understand and express ionic bonds using their structures and processes.	
Attitude	Explain the solution to a problem related to the issue of chemical bonds.	

The data analysis technique used to determine students' chemical literacy skills is based on the results of students' chemical literacy tests. The data obtained will be analyzed descriptively quantitatively against the increase in students' chemical literacy skills after being taught with the PBL model. The categories of chemical literacy skills can be seen in Table 3. Then, four aspects of chemical literacy are explained, namely content, context, HOLS, and attitudes, based on students' chemical literacy test answers.

Table 3. Chemical Literacy Ability Category

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

(Source: Ruslan & Agus, 2024)

RESULTS AND DISCUSSION

The lesson study practice applied in this study was carried out in 2 cycles, with each cycle consisting of a plan, do (open class), and see, especially on the ionic bond material. Before the lesson study was implemented, preliminary activities were carried out, and a more complete explanation is in Table 4.

Table 4. Preliminary Learning Activities

No.	Type of Introductory Activities	Activity Results
1	Analysis of Learning Problems on Campus (FGD of Chemical Engineering Lecturers and Practitioners)	The results of this discussion are as follows. 1. No learning resources can help students understand that the application of basic chemistry is very close to the environment. 2. During learning, lecturers use textbooks, scientific articles (journals/proceedings), and PowerPoint. 3. There has been no learning model that can encourage students to participate actively. 4. Lack of class management.

No.	Type of Introductory Activities	Activity Results
2	Interview with students who have taken basic chemistry courses	The following is the information obtained after interviews with students who have taken basic chemistry courses. (1) Chemical bonding material includes abstract theories but must be understood well by students. The material presented should be linked to problems in the surrounding environment so that it looks more real. (2) Lecturers have tried to help students understand the concept of chemical bonds, for example, by providing sample images and using three-dimensional models (molimo), but these efforts did not last long because students could not apply their knowledge to solve the chemical bonding problems given. (3) The images provided do not depict the microscopic side and provide examples related to life during learning. (4) Chemical bonds have a submicroscopic concept because they study the formation of bonds of an element, which is quite tricky for students to understand. (5) Students prefer practical work to listening to lectures in class because, in practical work, students carry out real activities and gain fundamental understanding.
3	Problem Analysis in Industry (Environmental Office)	The problems faced by Environemnetal Office include the following: (1) Piles of garbage make the conditions around the TPA smelly, resulting in air pollution. This condition will be exacerbated when the rainy season arrives. (2) Piles of garbage also disturb residents in the surrounding area because leachate seeps into the river and spreads to the residents' rice fields. As a result, the rice fields cannot be used to plant rice because the soil is damaged by leachate. (3) Leachate seeping into river water also causes the colour of the river water to turn black and smelly.

Based on the results of the analysis of the preliminary activities, learning planning and development of teaching materials were prepared at the Plan stage. The learning model that will be applied is a problem-based learning model where environmental problems used in learning are related to environmental pollution by leachate. A series of PBL activities consisting of (1) Providing problem orientation to students, (2) Organizing students in learning, (3) guiding student investigations independently or in groups, (4) Developing and presenting results, (5) Analyzing and evaluating the problem-solving process.

Open Class 1

In the open class 1 activity, the model lecturer carried out learning on the ionic bond material according to the learning implementation plan that had previously been designed together at the PLAN stage. In addition, the lecturer also prepared student worksheets, PowerPoint learning media, learning videos, chemical literacy questions on ionic bond material and observation sheets to make it easier for observers to observe the learning. In the worksheet, there was a discourse on questions related to leachate from the Mrican Ponorogo East Java TPA, which the environmental office handled. Students were asked to analyze the elements, mixtures, and compounds in the leachate. Then, from the existing compounds, students were asked to determine which ones were ionic compounds. After the open class activity was completed, the team of lecturers carried out SEE activities to discuss the learning findings, especially related to the activities carried out by students.

Open Class 2

Based on input from observers, the team of lecturers implemented learning improvements at the Redesign Stage. Some of the improvements made were adding chemical literacy practice questions to student worksheets, paying special attention to passive students, and changing the seating arrangement into small groups because previously, students discussed only with their deskmates.

Data collection on students' chemical literacy skills was carried out before opening class 1 and after opening class 2. The data taken are given in Table 5 below.

Table 5. Categories and Percentage of Student Chemical Literacy

Category	Test scores	Pretest		Postest	
		Number of Students	Percentage	Number of Students	Percentage
Low	< 61	8	41,2 %	5	29,4 %
Medium	61 – 84	7	47 %	9	52,9 %
High	> 84	2	11,8 %	3	17,7 %

Students' chemical literacy abilities increased, especially in ionic bonding material, before and after being taught with PBL learning. The purpose of giving pretest questions is to determine students' initial knowledge and misconceptions experienced by students in the chemical bonding material (van Dulmen et al., 2022). The chemical literacy test results showed that the student sample had moderate chemical literacy abilities. Students with moderate abilities have multiple chemical literacy criteria that are not fulfilled (Anggraeni et al., 2022). Chemical literacy covers four aspects, namely (1) knowledge of science and chemical content, (2) chemistry in context, (3) high order learning skills and (4) attitude (Cigdemoglu et al., 2017; Shwartz et al., 2006; Thummathong & Thathong, 2016). The students' chemical literacy ability test results can reveal the results of each aspect of chemical literacy. The following is a more detailed explanation of each aspect of chemical literacy produced in this study.

Knowledge of Science and Chemical Content

Content knowledge refers to the theories and concepts applied to understand a phenomenon (Vashti et al., 2020). Students' ability to explain how an element becomes stable through scientific study, generalize findings, and explain natural phenomena as well as occurrences in other fields is evaluated by the chemical literacy test on content (Wardani et al., 2024). The data collection instrument for the chemical content knowledge aspect uses two-tier choice diagnostic test questions.

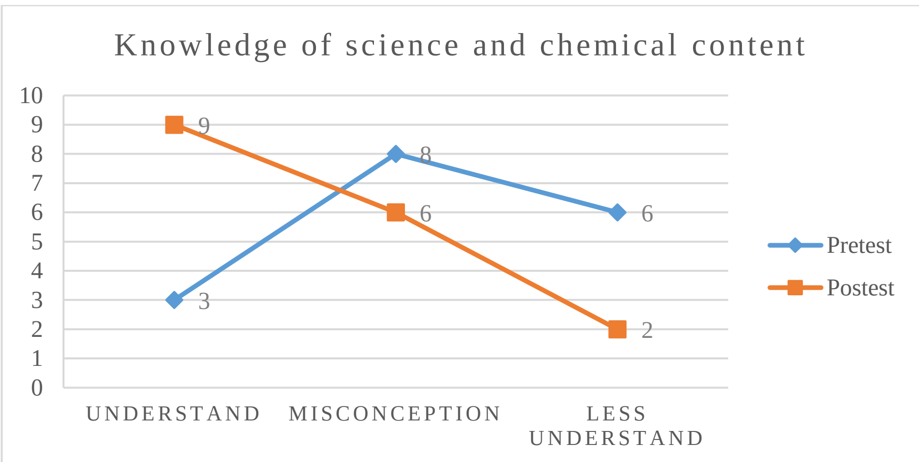

Figure 1. Literacy Test Assessment Results on Aspects Knowledge of Science and Chemical Content

Students are given a discourse on the process of making food, namely pizza, where the components for the pizza cooking process are components in the form of ionic compounds. In the questions, students are required to apply the concept of ionic bonds in the formation of ionic compounds with Lewis structures. After being given PBL learning and chemical literacy practice questions, the results of the study showed that there was an increase in students' understanding of the concept and a decrease in the number of students who experienced misconceptions and did not understand the concept.

The number of students who experienced student misconceptions was quite large. This misconception can occur because students are still unable to associate the process of forming ionic bonds with the properties that occur between the elements that form ionic compounds. Students are still confused about the formation of an ionic compound if given a Lewis structure depiction. Some students assume that magnesium ions and oxygen ions, when bound, will form MgO_2 ions because the electron valence of magnesium and oxygen ions is 2 and 8. In chemical theory, when magnesium and oxygen form an ionic compound, magnesium will release 2 electrons to form Mg^{2+} ions. In comparison, oxygen will receive 2 electrons from Mg to form O^{2-} ions and will form MgO ion compounds.

Chemistry in Context

The chemical aspect in context is an understanding of the main facts, concepts, and explanatory theories that build the foundation of scientific knowledge (Shwartz et al., 2006). Students are given a discourse on the process of making food, namely pizza, where the components for the pizza cooking process are composed of ionic compounds. In the questions, students are required to be able to use chemical knowledge in order to solve problems in everyday life.

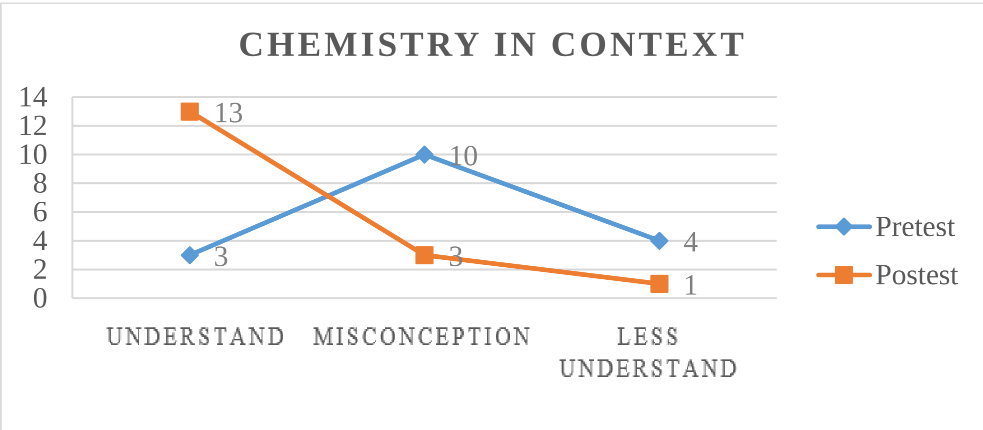

Figure 2. Literacy Test Assessment Results on Aspects Chemistry in Context

The results shown in Figure 2 show that the number of students who understand the concept has increased, and the number of students who misconstrue and do not understand the concept has decreased. Many students already know that the components of pizza baking contain ionic compounds, where ionic compounds are formed from metal and non-metal elements. Ionic compounds are formed by the transfer of electrons between atoms to create electrically charged particles and have an attractive force (Brady, 1994). The attractive force between oppositely charged ions is an ionic bond.

HOLS (High Order Learning Skills)

The next aspect of chemical literacy is the HOLS (High Order Learning Skills) aspect, which is the ability to identify questions from information related to content and contests and to analyze problems that occur (Schwartz et al., 2006). This HOLS aspect is measured using a chemical literacy instrument in the form of essay questions developed by Rizki & Yusmaita (2021), with a scoring system using literacy levels.

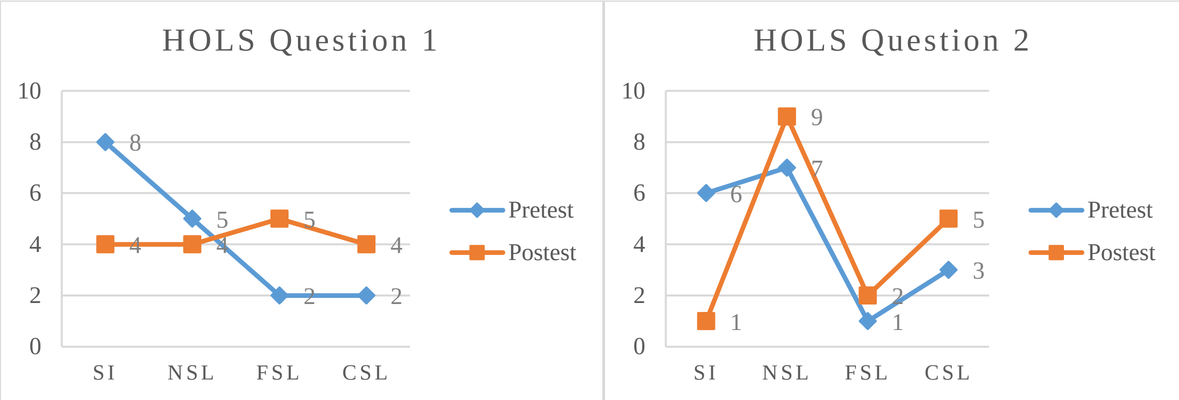

Figure 3. Literacy Test Assessment Results on Aspects HOLS

In HOLS questions 1, students are given discourse related to what causes seawater to be salty, and there is information about the content of ionic compounds in seawater. Students are required to explain what type of chemical bonds are formed and how the Lewis structure of the compound is depicted. The results of students' answers during the pretest and posttest show that at the scientific illiteracy (SI) and nominal scientific literacy (NSL) levels, there has been a decrease. In contrast, the Functional scientific literacy (FSL) and Conceptual scientific literacy (CSL) levels have increased. The most significant number of student answers is at the FSL level, where students provide answers according to the concept. Still, the explanation given shows a limited understanding of the concept. In HOLS questions 2, several ions are presented, and students are asked to find possible compounds that have been formed and explain the formation process.

The results of the students' answers during the pretest and posttest show that at the SI literacy level, there has been a decrease, while the NSL, FSL, and CSL levels have increased. In this question, it can be seen that five students have a CSL literacy level, which shows that many students can provide good answers according to the concept and can even connect with other chemical concepts. However, many students also get the NSL literacy level, which means that students only answer the possibility of the compound without providing supporting reasons for the formation process of the ionic compound.

Problem-based learning (PBL) can be effective in enhancing conceptual scientific literacy, but its success depends on several factors. While PBL can foster critical thinking and engagement, some studies suggest it may not always lead to superior test performance compared to conventional methods, especially when the focus is on mastering specific scientific concepts. Effective PBL implementation requires careful planning, student preparedness, and teacher expertise (Pakpahan, 2022; Suryanti et al., 2024). In this study, even though the lecturer had prepared learning tools, the students' readiness in implementing the PBLL model was low. Students need to have a foundation of basic scientific knowledge to be able to engage effectively with PBL problems.

Attitude

The attitude aspect is the ability to provide an attitude in solving problems related to phenomena or issues about chemical bonds (Shwartz et al., 2006). This attitude aspect is measured using an instrument where the literacy level given is only 2, namely the SI and NSL levels. In the chemical literacy questions, this aspect is given a discourse on microplastic compound pollution in the sea. Students are asked to provide opinions related to the efforts that must be made to overcome pollution.

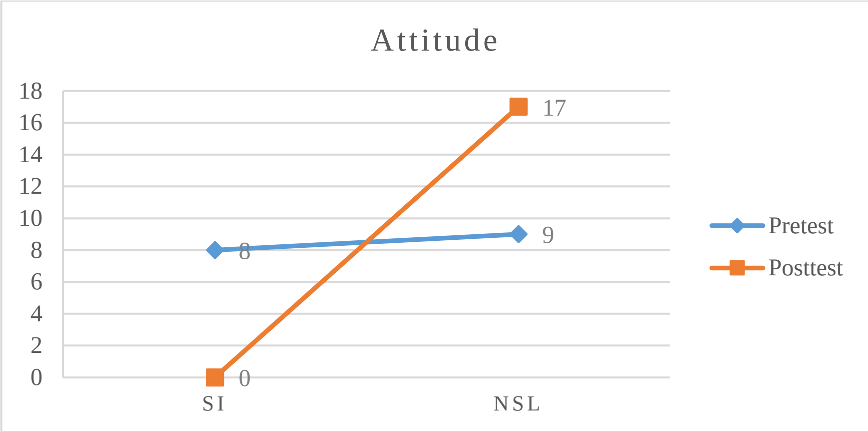

Figure 4. Literacy Test Assessment Results on Aspects Attitude

The results of students’ answers in the pretest and posttest experienced significant changes. It can be seen from the results of the posttest answers that the level of student literacy is at the highest level, namely NSL. Students can provide correct answers according to the concept of preventing microplastic pollution in the sea.

Overall, students’ chemical literacy skills can be improved by continuing to enhance supporting factors in the learning process. In this study, it was seen that students’ chemical literacy skills with problem-based learning had not been able to provide significant changes. This can be seen because students are not yet accustomed to a learning activity that emphasizes mastery of chemical knowledge. In order for pupils to become independent learners, instruction that stresses orienting them to real-world contexts is necessary (Arends, 2008). The learning model and educational materials influence the development of the ability to become chemically literate (Sutiani et al., 2022).

Chemical literacy skills can be improved by routinely providing reading materials about chemical literacy to students that are related to scientific phenomena and in accordance with the context of everyday life (Ruslan & Agus, 2024). In addition, chemical literacy skills, especially in the concept of chemical bonds, can also be improved by using teaching materials such as chemical literacy practice questions, teaching materials, textbooks, and relevant learning media. Several studies have been conducted in the development of teaching materials, including the use of e-Cartoons to improve chemical literacy skills on the topic of ionic and covalent bonds (Hasanah et al., 2024) and literacy worksheets on chemical bonding material (Adytia & Dwiningsih, 2018).

CONCLUSION

Based on the results of the analysis of this study, it can be concluded that environmental problem-based learning can improve students’ chemical literacy skills through the practice of lease study, although the increase is not significant. Students’ chemical literacy skills are at a moderate level. In the aspects of Knowledge of Science and Chemical Content and Chemistry in Context, the number of students who understand the concept has increased, and the number of students who misconstrue and do not understand the concept has decreased.

In the HOLS aspect, the most significant number of student answers is at the FSL level in terms of explaining the types of chemical bonds and depicting Lewis structures and in the explanation related to the possibility of compounds formed and the formation process of certain elements, the most significant number of student answers is at the NSL level. In the aspect of attitude, learning outcomes show that the most significant number of student answers is at the NSL level.

RECOMMENDATIONS

In this study, it can be seen that students' chemical literacy skills with environmental problem-based learning have not been able to provide significant changes. Therefore, further steps are needed to improve the learning process that can support students' chemical literacy skills. Other researchers who will use it to improve students' chemical literacy skills can pay attention to teaching materials such as worksheets, learning media, and evaluation tools that are suitable for use in the learning process on specific chemistry topics. Then, in further research, researchers should use a combined quantitative and qualitative approach to obtain a complete description of the lesson study activities.

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