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DEVELOPING STUDENTS' CHEMICAL LITERACY THROUGH THE INTEGRATION OF DILEMMA STORIES INTO A STEAM PROJECT ON PETROLEUM TOPIC

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Abstract

The aim of this study was to develop students' chemical literacy by integrating dilemma stories into a Science, Technology, Engineering, Arts, and Mathematics (STEAM) project on petroleum. Chemical literacy can help students face future challenges by applying what they learn about chemistry subjects at school to solve problems in their daily lives. A qualitative research method was employed that included interviews, observations, reflective journals, chemical literacy tests, and student activity sheets, as data collection tools. Thirty six secondary school students participated in the research using a project-based approach consisting of five steps: value reflection, problem-solving, project monitoring and evaluation, project development, and transformation. This study used four chemical literacy components according to Shwartz, Ben-Zvi and Hofstein (2006) namely scientific and chemical content knowledge, characteristics of chemistry, chemistry in context, higher-order learning skills, and affective aspect. STEAM integrated with dilemmas stories provides opportunities for students to develop chemical literacy through value reflection, problem solving, and STEAM project. This study uses a dilemma story to understand chemistry concepts whereby students can develop a project by integrating chemistry and STEAM principles. The STEAM Project involved making alternative fuel to find a solution to a problem presented in the dilemma story. The researchers were challenged by the need to find a suitable chemistry-based dilemma story to integrate with a STEAM project while also empowering students and managing time resources.

Keywords – Chemistry learning, Dilemma stories, STEAM project, Chemical literacy, Petroleum.

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1. Introduction

Low literacy levels in education affect the quality of school graduates. The education process in Indonesia is still oriented towards producing graduates who are focused on the content knowledge aspect of learning. The demands of academic achievement are either indicator of good or not learning is in the classroom, thus making teachers focused solely on delivering material and ignoring the demands to develop a student's literacy that will enable them to compete in a global economy and other fields. Papen (2005) states that low literacy rates, an issue in many countries, affect the quality of human resources and an employee's involvement in society. This information supports the need to improve the quality of education in developing student literacy levels, especially scientific literacy.

Scientific literacy is considered an important factor in helping students make effective knowledge-based decisions and to be able to apply the concepts they learn to solve existing problems (National Research Council, 2012). Comprehensive survey tools for assessing scientific literacy internationally are Trends in Mathematics and Science Studies (TIMSS) and the Programme for International Student Assessment (PISA). TIMSS is a student mathematics and science attainment study run by the Achievement Association for the Evaluation of Educational Achievement (IEA). The results of the IEA's 2011 survey of science at the secondary education level indicated that Indonesia was ranked 45th out of 48 countries (IEA, 2012). Meanwhile, based on the 2018 PISA survey, Indonesia ranked 67th out of the 81 countries tested in scientific literacy (OECD, 2023).

Chemistry is the branch of science that focuses on the nature and interaction of the matter of a substance (Gilbert & Tragust, 2009). Chemistry learning involves three representations: macroscopic, microscopic, and symbolic and is challenging for students (Chandrasegaran, Treagust & Mocerino, 2008). These three representations help educators to develop student competencies in chemistry and their understanding of concepts by presenting chemistry as interrelated.

Chemistry is important for students to learn, as many phenomena in life are related to chemistry (Cigdemoglu, Arslan & Cam, 2017; Sirhan, 2007). According to Shwartz et al. (2006) chemical literacy is the ability of students to know and apply their knowledge of the four components of chemical literacy; scientific and chemical content knowledge, chemistry in context, high-order learning skills, and an affective aspect. Research indicates that low chemical literacy in students and education held has not been able to fully build chemical literacy (Prastiwi & Laksono, 2018).

Efforts to improve students' chemical literacy skills, focus on contextual and student-centered learning activities. Contextual learning is a learning strategy that emphasizes student engagement overall by connecting concepts learned with real life, thus encouraging students to apply them in daily life (Dewey, 1985). The application of this contextual learning activity is very appropriately applied in chemistry learning to develop the chemical literacy of students.

Contextual learning can be used to improve students' chemical literacy by integrating dilemma stories into STEAM projects, thereby encouraging students to apply chemistry concepts to everyday life. Dilemma stories raise complex problems that trigger an emotional response whereby teachers can educate students to think critically, cooperate, accept or negotiate ideas, and solve problems (Rahmawati, Ramadhani, & Afrizal, 2020).

The dilemma stories approach was first introduced in science learning by Taylor to improve the teaching of science that associates social issues with content (Taylor, Taylor & Chow, 2013). The approach develops collaborative problem-solving skills, encourages evidence-based decisions and critical thinking, skills consistent with the development of scientific literacy (Settlemaier, Taylor & Hill, 2010). Dilemma stories educate students to think critically, work together, accept, negotiate ideas, and solve problems about dilemmas faced in their daily lives (Rahmawati, Nurbaity & Marheni, 2014). The STEAM approach is then used to create projects aimed at solving the social issues presented in the dilemma story.

The STEAM approach is a further development of STEM (science, technology, engineering, and mathematics), first introduced in the United States to increase the number of students studying in STEM fields (Gonzalez & Kuenzi, 2012). Learning with the STEAM approach contextualizes learning by inviting students to understand the phenomena that occur around them (Yakman & Lee, 2012). Learning with the STEAM approach is a breakthrough for education in Indonesia in that it seeks to develop teachers who can teach students critical thinking and develop techniques or designs to solve problems in the world based on mathematics and science.

STEAM has proved to be effective developing high-level thinking skills, collaboration, argumentation, and creativity in chemistry students (Hadinugrahaningsih, Rahmawati & Ridwan, 2017). It has also been effective in developing analytical thinking skills and attitudes towards science learning (Chonkaew, Sukhummek & Faikhamta, 2016).

Studies have shown that the integration of dilemma stories with a STEAM approach can help develop students' chemical literacy and contextual understanding. It involves collaborative interaction in working groups while creating projects to solve everyday problems Therefore, further analysis of the improvements of student chemical literacy by integrating dilemma stories with a STEAM project on chemistry learning is the focus of this project.

2. Methodology

The study employed a qualitative case study research design with data collected from interviews, observations, reflective journals, students' daily activities sheet, and chemistry literacy test. The chemistry literacy test questions were based upon the chemistry literacy skills rubrics of Shwartz et al. (2006). The activities were carried out through the stages of value reflection, problem-solving, project development, project monitoring, and evaluation, and transformation. The students were required to develop an alternative fuel STEAM project as a solution to the petroleum dilemma presented in the story. The stages of the process are shown in Figure 1.

As represented in Figure 1, learning activities were carried out using the petroleum dilemma presented in the story. The use of dilemma stories in the learning process encouraged students to find solutions to the problems presented through the creation of a STEAM project. The integration of dilemma stories into a STEAM project encouraged students to actively engage and collaborate in a working group and, in doing so, increased their chemical literacy.

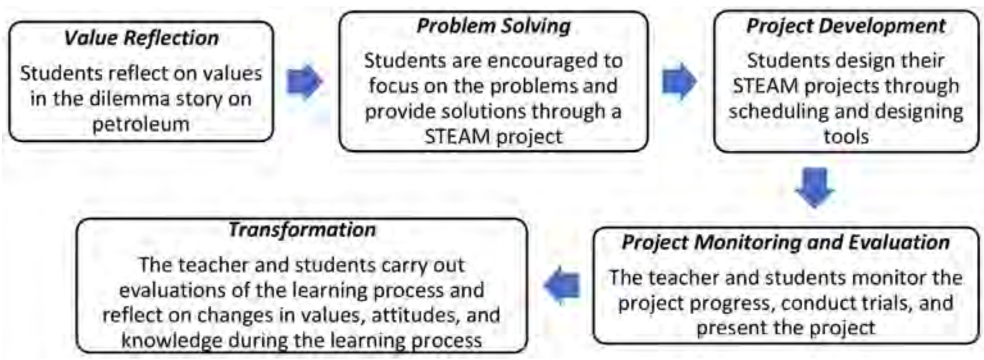

Figure 1. The Integration of the dilemma story and the STEAM project

2.1. The Participants

Thirty-six grade XI science stream students at a senior high school in Jakarta, Indonesia participated in the study. Of this number, 18 were males and 18 were females. Students' cognitive abilities in chemistry preparation varied from high to low.

2.2. Data Analysis

Qualitative data analysis techniques are carried out through the stages of reduction, display data, and conclusion drawing/verification (Miles & Huberman, 1994). The data obtained during the study through interviews, observations, reflective journals, students' daily activities sheets, STEAM project assessment, and petroleum open-ended test were reduced by selecting data was under the focus of chemical literacy. The data obtained during the study through interviews, observations, reflective journals, students' daily activities sheets, STEAM project assessment, and petroleum open-ended test were reduced by selecting data was under the focus of chemical literacy. At the data display stage, the data that has been reduced is then presented in the form of a matrix or coding based on the chemical literacy indicators so that data verification can be carried out and conclusions can be drawn. The coding of data used in grouping was based on the components of chemical literacy, 1) general scientific ideas, 2) characteristics of chemistry, 3) chemistry in context, 4) higher-order learning skills and 5) affective aspect (Shwartz et al., 2006). The results of the data presented are then concluded by giving meaning to the results of the data. The conclusions were then verified by checking their consistency and compatibility with other data collected. Quality standards used in this study were trustworthiness and credibility through prolonged engagement, persistent observation, progressive subjectivity, and member checking (Miles & Huberman, 1994) to test the validity and trustworthiness of the data (Guba & Lincoln, 1989). Persistent observation is carried out to explore various phenomena by involving researchers directly in the learning process. In making continuous and in-depth observations, the researcher was assisted by two observers to analyze the learning process and the development of students' chemical literacy. Progressive subjectivity is carried out to monitor research results with all notes obtained during the study based on the characteristics of students' chemical literacy. Member checking is done to ensure the accuracy of the data obtained from students as data providers regarding the various research results. All data obtained, both in the form of hard paper copies and interview transcripts, were kept privately by the researcher for the privacy of participants and confidentiality.

3. Results and Discussion

3.1. The Integration of Dilemma Stories and a STEAM Project for Learning the Petroleum Topic

The focus of this study was to determine the effectiveness of integrating dilemma stories with STEAM projects for developing students' chemical literacy. The total time required to integrated dilemmas stories in the STEAM project for 4 weeks in petroleum learning. At the preliminary stage, the researcher compiled an interview protocol for teacher and students to obtain information related to chemistry learning in school and students' chemical literacy. At this stage, the researchers also compiled a lesson plan using integrating dilemma stories with STEAM projects, developed dilemmas stories about petroleum, and compiling research instruments such as observation sheets, reflective journals, students' worksheets, the preparation and validation of open-ended petroleum test questions. The learning began by introducing petroleum materials and a petroleum dilemma story to the students. The story presented an issue aimed at encouraging students to think critically, collaborate, accept, negotiate ideas, and solve problems relate to everyday life. Students first reflected individually on the values in the dilemma story related to the petroleum topic. Students were then introduced to the petroleum material and to the concept of a STEAM project. Science was related to making the project. Technology required the students to use technology in making the project. Engineering meant the students had to know the working principles of alternative fuel. Art related to how the students designed the project and Mathematics related to the application of mathematical skills required for making the project (Rahmawati, Ridwan, Mardiah & Afrizal, 2020).

At the next stage, problem-solving, students were encouraged to solve problems by creating a STEAM project as a solution to the problem presented in the dilemma story. At the problem-solving stage, students were given the opportunity to individually think of solutions to the problems in the dilemma story, prior to a group discussion. As a result of the class discussion, students created an alternative fuel project, based on STEAM approach, as a solution to the dilemma presented in the story. The process is captured in Figure 2.

The students were required to create an alternative fuel in 6 teams of 6 students with each team providing a different solution to the dilemma. The students began the project by developing an alternative fuel design, they then determined what materials were required to build it and these details were recorded on an activity sheet. The process provided opportunities for students to develop critical and creative thinking skills and to increase their involvement in the learning (Rahmawati, Ridwan, Hadinugrahaningsih & Soeprijanto, 2019). Students and teachers discussed the development of a timeline as a guide for students to complete the project in a timely manner.

The monitoring and evaluation phase was then carried out. At this stage, the researchers were assisted by an observer who monitored the activities and the progress towards completion in relation to the academic calendar. Monitoring activities in the study were conducted during two meetings, then evaluation activities, including testing and presenting the project were conducted at the next meeting. The first monitoring of student project progress is shown in Figure 3. Monitoring was carried out on November 27, 2019.

Figure 2. Students solving the problem

Figure 3. First Monitoring of Student Project Progress

During the learning process, time was divided between delivering petroleum material, and project activities. The students' started working on the project enthusiastically as demonstrated by the following observations.

> *"When delivering the petroleum material, some students looked less enthusiastic because of the last class, but it was different when they started working on the project, the students looked very enthusiastic."* (Observation sheet, November 27, 2019)

This view is supported by Salam, Mailok, Ubaidullah and Ahmad (2016) who stated that the application of project-based learning is effective in building student involvement in learning.

The student activities during testing the tool is shown in Figure 4. In testing the tools, students measured the success rate of the project that has been created to identify if there were deficiencies in the project so that improvements could be made. Test results showed that the tools made by students functioned correctly according to the purpose of making them to substitute petroleum and other fossil fuels commonly used in daily life. Figure 5 shows some of the solutions developed by the students.

A presentation of the project completed by each group was conducted aimed at testing students' understanding of the project they created. Students presented their project to the other groups, as pictured in Figure 6.

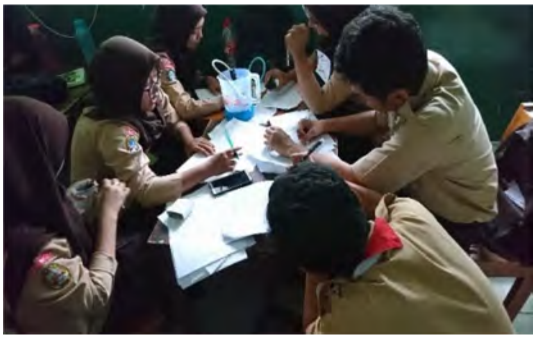

Figure 4. Student Activities during Testing the tool

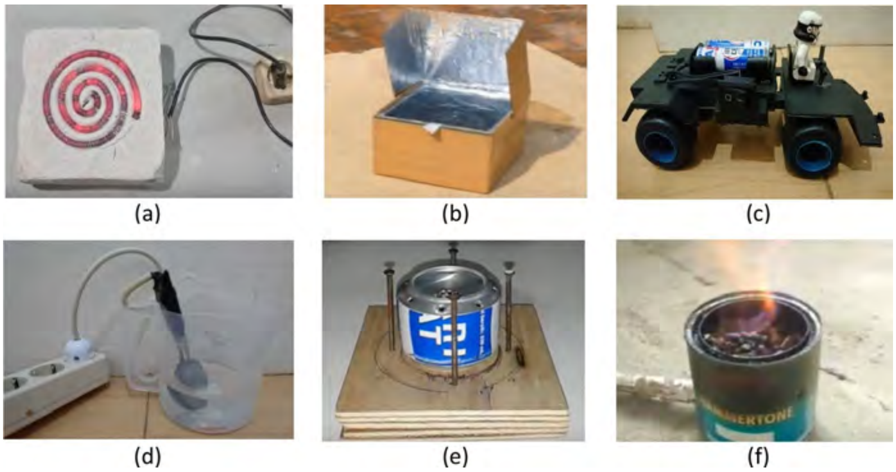

Figure 5. Alternative fuel STEAM Projects: (a) a simple electric stove, (b) a solar stove, (c) a miniature electric car, (d) an electric teapot, (e) a simple stove with biodiesel fuel, and (f) a stove with briquette from rice chaff

Figure 6. Group Presentation

Presentation activities allow students to develop communication skills as they conveyed the results of their activities to their classmates who asked questions, and provided critique and suggestions.

Student 6: Why do you use used oil to make biodiesel?

Student 31: To be more efficient and economical

Student 9: To reuse unused oil, thereby reducing oil waste in the environment

(Researcher's field notes, December 11, 2019)

The above conversation shows that students were able to ask about the main ingredients of product manufacturing. Responding students provided good reasons related to the selection of used oil as the main ingredient of biodiesel manufacturing, namely as the reuse of used oil and to reduce oil waste in the environment. Through this question and answer process, students developed their high-level thinking skills to improve critical thinking, aligning with one of the standards of critical thinking ability according to Paul and Elder (2007) that students can ask questions in their language and answer questions by presenting the reasons clearly and plausibly.

The final product, created in the learning activity required STEAM components to be integrated. The results of the product assessment shows that the average value of the product developed by students was good based on the requirement that the products were manufactured according to the design, they fulfilled STEAM components, could replace the use of petroleum in the form of gasoline and LPG for daily life, and they completed the task in the allocated time agreed by the students. Students were enthusiastic about their learning because they created a product by working together as a team. At the transformation stage, students evaluated the learning process and reflected on changes in their values, attitudes, and knowledge. They reflected on the constraints experienced during the learning process, the solutions students provide during project completion, and their feelings during learning activities. The implications of using dilemma stories integrated with STEAM projects were captured through reflective journal entries.

> *"In my opinion, learning with dilemma stories and STEAM projects is very appropriate because we learn in an organized, orderly manner, and our skills are honed through the given problem so that students think critically to find the right solution. The resulting solution in the form of a project can hone the creativity of students in addition to being able to understand the lesson well."* (Student 12, Reflective journal entry, December 11, 2019)

The reflective journal entry above shows that student 12 agreed that learning by integrating dilemma stories into STEAM projects can develop their critical thinking and creative thinking skills; a view is supported by Rahmawati et al. (2019) who states that the integration of STEAM projects in chemistry learning can develop students' critical thinking and creative thinking skills. In developing the project, students were encouraged to use a variety of information sources and materials, and to take into account time that might need to be allocated to complete the project, so that they chose the right strategy. Students also reflected on the learning process and the development of motivation and involvement during collaborative interactions and individual responsibilities in the group. Project-based learning strategies challenge students to work together in groups to solve problems presented in dilemma stories, to test ideas and present the results in front of the class, thereby increasing the motivation and involvement of all students in their learning (Wurdinger, Haar, Hugg & Bezon, 2007).

3.2. Student's Chemical Literacy in the Learning Process

Chemical literacy is the ability of students to know and apply their knowledge of the content of such science, as well as of it in context, of higher-level learning skills and of the affective aspect. Learning chemistry is therefore a challenge for students and involves macroscopic, microscopic and symbolic representations, which help educators to develop the competencies of chemistry students, as well as the understanding of concepts, by presenting it as something interrelated, since many phenomena in life are related to it. Participating students were observed as they applied their chemical literacy understanding to a STEAM project using a dilemma story. The chemical literacy indicators observed were categorized as general scientific ideas, characteristics of chemistry, chemistry in context, higher-order learning skills, and affective aspect (Shwartz et al., 2006). Each aspect of chemical literacy was divided into 5 categories, i.e. very low, low, moderate, good, and excellent. At the final stage, students are given open-ended tests to assess their understanding on petroleum topic and students' chemical literacy. The open-ended test consisted of five essay questions compiled by researchers based on basic competencies and petroleum learning indicators in the 2013 curriculum. The open-ended test aimed to determine students' chemical literacy as an implication of integrating the dilemmas stories in the STEAM project. In this study, open-ended questions were validated by 3 experts consisting of 2 Chemistry Lecturers and Chemistry Education Lecturers at Universitas Negeri Jakarta and 1 high school chemistry teacher in grade 11.

3.2.1. General Scientific Ideas

The Aspect of general scientific ideas measures students' ability to carry out scientific investigations, generalize findings, and propose theories to explain natural phenomena, and to use knowledge to explain phenomena in other fields such as earth sciences and biology (Shwartz et al., 2006). Analysis of the chemical literacy test on general scientific ideas showed that 63.89%, or as many as 23 students, reached an excellent level of achievement, meaning that most students were able to conduct scientific inquiries, make generalizations, propose theories to explain the natural phenomena and use knowledge to explain phenomena in other fields. This is supported by the statements students made during discussion using a dilemma story.

Student 11: According to my group, excessive use of petroleum such as gasoline use can lead to global warming because it produces CO_2 *gas as a result of combustion.*

Student 7: Besides, petroleum is non-renewable energy that will one day run out due to its very long manufacturing process for millions of years.

Student 25: If that is the case, we should look for alternative energy sources that can substitute petroleum as well as environmentally friendly.

(Observation sheet, November 20, 2019)

The above transcript shows students were able to generalize the findings and come to an appropriate conclusion.

33.33%, or as many as 12 students reached a good level of general scientific ideas, meaning that some students could carry out scientific investigations, make generalizations and try to explain the natural phenomena and use knowledge to discuss phenomena in other fields. These results were reinforced by the students' conversations captured on the observation sheet.

Student 31: Miss, if based on the information provided, should we choose gasoline should match the compression ratio of the vehicle engine we use? Is that true?

Researcher: Yes, that's right. Why do we have to adjust to the engine of the vehicle we use?

Student 26: So that the use of gasoline is not wasted quickly, and does not produce pollution from combustion results that can result in negative environmental impacts.

Researcher: Approximately any type of emissions or substances produced by the combustion of gasoline which can be bad for the environment?

Student 22: For example, CO substances are the result of imperfect combustion that can interfere with breathing.

(Observation sheet, 20 November 2019)

The above observations shows that some students were able to investigate the relationship between the type of gasoline to be used and the compression ratio of the vehicle's engine. The students were also able to explain the dangers of imperfect combustion results in CO substances that can interfere with breathing by interfering with the function of hemoglobin in binding to oxygen. This response aligns with the theory that imperfect combustion can produce carbon monoxide (CO), or sometimes carbon in the form of charcoal or soot (Fessenden & Fessenden, 1982).

2.78%, or only 1 student reached moderate levels of general scientific ideas, demonstrating that they had begun to carry out scientific investigations, generalize findings, and had made an attempt to put forward theories to explain natural phenomena and use a bit of their knowledge to discuss phenomena in other fields, such as earth science and biology. The results of achieving this level are demonstrated in the following interview.

Researcher: Why is the use of petroleum, such as gasoline done excessively considered harmful to the environment? Try explaining!

Student 2: Excessive use of gasoline is not good because it produces substances from gasoline combustion results that can cause air pollution. (Student 2, Interview, December 11, 2019)

The response above shows that student 2 used some knowledge to explain phenomena in other fields and they tried to explain the impact of excessive use of gasoline which causes air pollution. The student was not able to explain what compounds are produced from the combustion process that can cause air pollution.

0% of students achieved low or very low on general scientific ideas indicating that all students tried to carry out scientific investigations and to generalize their findings by trying to put forward theories to explain natural phenomena and phenomena in other fields.

3.2.2. Characteristics of Chemistry

The characteristics aspect of chemistry is the skill of chemical literacy in explaining macroscopic phenomena in the form of molecular structures of matter, investigating process dynamics and reaction equations. Based on the analysis of students' chemical literacy tests, 33.33%, or 12 students, reached an excellent level. The results indicate that these students were able to explain macroscopic phenomena in the form of material molecular structures, and investigate process dynamics and reaction equations as demonstrated by the following response to the chemical literacy test of combustion reactions of propane compounds contained in LPG.

$$C_3H_{8(g)} + O_{2(g)} \rightarrow 3CO_{2(g)} + H_2O_{(g)}$$

(Student 1, Chemical literacy test)

Test results show that students were able to write down the perfect combustion reaction equation for propane. The perfect combustion of a compound will produce CO_2 (carbon dioxide) and H_2O gases (Fessenden & Fessenden, 1982). The achievement of excellent levels in the characteristics aspect of chemistry was also shown in the following observation results where the student carried out a precise reaction to the combustion reaction from gasoline.

"Researcher allowed students to work on the question of writing down the equation of perfect combustion reaction in gasoline, with its main content of octane compound (C_8H_{18})"

$$2\ C_8H_{18\ (l)} + 25\ O_{2(g)} \rightarrow 16\ CO_{2(g)} + 18\ H_2O_{(g)}$$

(Observation sheet, Student 22, 20 November 2019)

36.11%, or as many as 13 students, achieved a good level in the aspect of characteristics of chemistry. These results indicate that some students can discuss macroscopic phenomena in the form of material structures. This level of achievement is shown in the following student interviews.

Researcher: What compounds can cause acid rain?

Student 10: Compound NO_2, Miss.

Researcher: Where did the compound produce?

Student 10: From vehicle smoke and factory smoke.

Researcher: Why can the compound cause acid rain?

Student 10: Because it will form the HNO_3 compound from the reaction between NO_2 and H_2O, so it can result in acid rain.

(Student interview, December 11, 2019)

The interview response above indicates that the student could explain the process of acid rain resulting from vehicle smoke and factory smoke. The student was also able to explain the formation reaction of the HNO_3 compound, causing acid rain. However, they did not mention that NO_X or NO_2 compounds are produced during combustion by using air as a source of oxygen and air containing nitrogen gas (N_2). At high temperatures, a reaction between nitrogen and oxygen can occur inside a vehicle to form NO_X or NO_2 gas.

22.22%, or as many as 8 students, reached moderate levels in the characteristics aspect of chemistry. These results indicate that some students could briefly explain macroscopic phenomena in the form of molecular structures of matter. This is shown in the following researcher's field notes.

Researcher: Does anyone know the difference from a perfect combustion reaction with an imperfect combustion reaction?

Student 6: From the result of the burning, Miss.

Researcher: What is the result of combustion?

Student 6: The result of perfect combustion produces CO_2 gas while if the imperfect combustion produces carbon monoxide (CO) and carbon gases.

(Researcher's field notes, November 20, 2019)

The above conversation indicates that student 6 could briefly explain the difference between a perfect combustion reaction and an imperfect combustion reaction based on the results of the reaction.

8.33%, or as many as 3 students reached a low level in the characteristics aspect of chemistry based on the results of chemical literacy tests. This result shows that a small proportion of students can only briefly explain macroscopic phenomena using general knowledge as demonstrated by the following interview.

Researcher: Why is the use of petroleum such as gasoline, if excessive use is considered harmful for the environment?

Student 5: Because when gasoline is burned it will produce carbon dioxide gas that can result in air pollution.

Researcher: What are the main compounds of gasoline forming? And try to describe the combustion reaction so that it produces CO_2.

Student 5: Miss…I forgot the main compound, for the result of the reaction there are CO_2 and H_2O gases.

(Student interview, December 11, 2019)

The results of the interview showed that student 5 could only briefly explain the air pollution caused by the combustion of gasoline in the form of carbon dioxide gas. The student did not explain the combustion reaction that occurs in gasoline resulting in carbon dioxide (CO_2) gas indicating that some students are still at a low level in the aspect of characteristics aspect of chemistry.

"But there are still some students who do not appropriately write the perfect combustion reaction on propane, for example: $2C_3H_8 + 3O_2 \rightarrow 3C_2O + 3H_2O$."

(Researcher's field notes, November 20, 2019)

The researchers' field notes indicate that during the learning process some students were not able to write down the perfect combustion reaction that occurs in propane.

Based on the results of chemical literacy tests no student scored 0%, indicating that all students could explain something about the macroscopic phenomenon. However, during the learning process it was found that some students were still at a very low level.

"Some students forget and are confused about how to write down the equation of the combustion reaction that occurs in gasoline with its main content in the form of octane (C_8H_{18})."

(Researcher's field notes, November 20, 2019)

Based on the explanations above, research results show that students already had good chemistry literacy ability on aspects of characteristics chemistry, meaning that they were able to explain macroscopic phenomena in the form of material molecular structures, investigating process dynamics and reaction equations. The ability to explain macroscopic phenomena at a microscopic level is important for students to be able to understand modern science and other sciences (Johnstone, 1991).

3.2.3. Chemistry in Context

Chemistry in context measures a person's ability in terms of 1) seeing the relevance and usefulness of chemistry in everyday life, 2) the use of chemical knowledge in explaining everyday phenomena, 3) the use of a broad understanding of chemistry in daily life, and 4) having an understanding of the relationship between chemical innovations in socio-cultural life (Shwartz et al., 2006). The results of the chemical literacy test analysis in the chemistry in context aspect showed that 77.78, or as many as 28 students, reached an excellent level. This result indicates that most students were able to use extensive chemical knowledge in explaining phenomena in everyday life to use in the decision-making process, as demonstrated by the following student's chemical literacy test results.

> *"To reduce the knock on the vehicle engine with a high compression ratio is done by increasing the octane value on gasoline. The addictive substance used to raise the octane value is MTBE (Methyl Tertiary Butyl Ether)."* (Student 10, Chemical literacy test)

The student's answers shows that they used their chemical understanding in determining addictive substances to be used to increase the octane in gasoline to reduce the knocks that occur on vehicle engines with high compression ratios. This is done so that the vehicle's engine is not damaged due to knocking and so that the use of gasoline is not wasteful and reduces the emissions produced in the combustion process. The use of extensive chemical understanding was needed to produce the right decisions.

22.22%, or as many as 8 students reached a good level in the aspect of chemistry in context, indicating that they were able to use chemical understanding in everyday life as shown by the following observations.

> *Researcher: As you know, there are many types of gasoline in gas stations. What distinguishes between different types of gasoline from each other?*
>
> *Student 2: The number of octanes, Miss.*
>
> *Researcher: Why is gasoline made with different octane numbers?*
>
> *Student 6: So that the gasoline we use according to the compression ratio on the engine of the vehicle.*
>
> *Researcher: Why is this necessary?*
>
> *Student 25: For gasoline to burn at the right time so that the maximum energy generated as well as exhaust gases from the combustion results less.*
>
> (Observation sheet, November 27, 2019)

The responses above show that these students used their chemical understanding in determining the gasoline to be used according to the compression ratio on the vehicle engine. This decision was made so that the combustion that occurs inside the machine runs effectively according to the time so that it produces maximum power, the use of gasoline is not wasteful, and the exhaust emissions are small. The decision also reduces the knocking of the machine which can damage the main components of the machine.

0% of students reached a moderate level in the aspect of chemistry in context indicating that all students could use chemistry knowledge to explain phenomena in daily life. However, based on the findings during the learning process, some students were still identified at this level.

> *Researcher: Do you think chemistry learning related to phenomena that exist in daily life?*
>
> *Student 27: There are, such as global warming and acid rain.*
>
> *Researcher: Why does this phenomenon occur?*
>
> *Student 27: It was caused by air pollution from vehicle and factory fumes.*
>
> (Student interview, December 11, 2019)

The results of the interview above show that students 27 used limited knowledge to explain phenomena that exist in everyday life. Students have knowledge of the phenomenon of global warming and acid rain caused by human activities such as vehicles and factory smoke.

0% of students reached low or very low levels based on the results of chemical literacy tests as demonstrated by the following observation.

"Students understand the importance of chemical knowledge about petroleum in daily life, students can explain the phenomena that exist in life based on their chemical understanding. Besides, students propose some suggestions or ideas related to the issue of petroleum use." (Observation sheet, 27 November 2019)

The explanation above shows that most students already have good chemistry literacy ability on the aspect chemistry in context, meaning that students are able to see the relevance and usefulness of chemistry, and use chemical knowledge to explain phenomena in their daily life. Chemical knowledge helps humans to make decisions on public issues and helps humans understand life and the environment (Tsaparlis, 2000). It is a crucial science closely related to everyday life (Gilbert & Tragust, 2009).

3.2.4. High-Order Learning Skills

High-order learning skills are aspects of chemical literacy that measure a person's ability to identify scientific issues, explain scientific phenomena, use scientific evidence, and evaluate the pros or cons of debate (Shwartz et al., 2006). The results of chemical literacy tests analysis on aspects of high-order learning skills showed 22.22% or as many as 8 students reached excellent levels, demonstrating that students can ask very good questions and seek related information. The results of chemical literacy tests showed that students can identify and explain scientific phenomena in the form of air pollution in urban areas. Students understood that the source of the pollutants comes from vehicles and factory fumes and could explain the dangers posed by these pollutants and find solutions to overcome pollution based on scientific evidence. The achievement of an excellent level in the aspect of high-order learning skills in the following interview transcript.

Researcher: Why is the use of petroleum such as gasoline considered dangerous if used excessively?

Student 16: Because it can cause acid rain due to the increase in SO_2 and NO_X gases resulting from fumes of vehicles.

Researcher: How does it impact the environment?

Student 16: Can disrupt the ecosystem of land and water, Miss.

Researcher: Why is this happen?

Student 16: Because many animals and plants cannot live on pH is too low. Acid rain can lower the existing pH in land and water.

(Student interview, December 11, 2019)

The above interview responses show that the student could explain the impact of excessive use of gasoline on the environment that can disrupt the ecosystems of the land and water and that SO_2 and NO_X gases come from fumes of vehicles which can cause decreased pH of rain from normal rain. In addition, the student could explain that animals and plants cannot live at too low a pH due to acid rain. The student's ability to explain scientific phenomena indicates the development of critical thinking skills (Raub, Shukor, Arshad & Rosli, 2015).

52.78%, or as many as 19 students, reached a good level in the aspect of high-order learning skills indicating that most students were able to ask questions and seek information regarding the questions asked. These students are also able to explain scientific phenomena as shown the following interview transcript.

Researcher: Why is the use of petroleum such as gasoline considered dangerous if used excessively?

Student 12: Because it can cause global warming due to an increase in CO_2 gas from gasoline combustion.

Researcher: How does it impact the environment and health?

Student 12: The temperature on the surface of the earth will increase, this can trigger skin cancer.

(Student interview, December 11, 2019)

The above interview shows that student 12 can explain the scientific phenomenon of global warming and connect their chemistry knowledge with the daily life they know. This is in line with a reference that mentions that contextual-based learning can stimulate students to connect their knowledge with phenomena in daily life to develop students' high-order learning skills (Raub et al., 2015).

25%, or as many as 9 students, reached moderate levels in the aspect of high-order learning skills demonstrating that most students could begin to explain scientific phenomena and to ask questions. However, they did not know how to find information regarding the questions asked, as shown in the following interview transcript.

Researcher: Why is the use of petroleum such as gasoline considered dangerous if used excessively?

Student 26: Because it can cause acid rain caused by vehicle fumes so that it can damage the ecosystem of the land and water because the pH of rainwater decreases.

(Student interview, December 11, 2019)

The interview above shows that student 26 began to explain the phenomenon of acid rain that can damage land and water ecosystems due to the decrease in pH from rainwater. However, the students did not explain the process of acid rain or the relationship of the decrease in pH of rainwater with the ecosystem of the land and water.

0% of students reached low levels in the aspect of high-order learning skills. However, in the learning process, some students were still trying to ask questions but did not seek related information. They partially explained scientific phenomena in daily life as shown by the following interview transcript.

Researcher: Why is the use of petroleum such as gasoline considered dangerous if used excessively?

Student 27: Because it can cause global warming caused by the fumes of vehicles.

Researcher: How does it impact life?

Student 27: The temperature on earth will get hotter, Miss.

(Student interview, December 11, 2019)

The interview above shows that student 27 could provide a limited explanation about the impact of excessive use of gasoline that can trigger global warming. The student did not relate to the use of gasoline that can produce air pollution in the form of CO_2 gas and global warming events.

0% of students reached very low levels in the aspect of high-order learning skills demonstrating that all students have an interest in explaining scientific phenomena based on their chemistry knowledge as shown by the following observation.

"Students can identify scientific issues about petroleum, and can explain phenomena that occur in their environment due to petroleum use using scientific evidence." (Observation sheet, 20 November 2019)

The research results above show that most students already have good chemical literacy ability on aspects of high-order learning skills. High-order learning skills include three metacognitive ability, argumentative ability, and good question-asking skills. The development of high-order learning skills needs to be developed because, in addition to providing students with an understanding of chemistry, they also educating students to be literate in the future so that they can use their chemical understanding in everyday life (Hofstein, 2015).

3.2.5. Affective Aspect

The effective aspect measures a person's ability to understand the impact of chemistry and its application and interest in chemical issues (Shwartz et al., 2006). The analysis of students' chemical literacy tests on the affective aspect showed that 83.33%, or as many as 30 students, reached excellent levels. This result indicates that most students have a strong interest in chemistry and can explain the impact of chemistry and its application in everyday life. The results of chemical literacy tests show that students have a strong interest in chemical issues raised related to the energy crisis when petroleum use is excessive. Students suggested the use of alternative energy sources to reduce petroleum use in daily life and explained where the energy source would come from. The students also responded to the excess and deficiency of alternative energy, such as gasoline, when compared to the use of petroleum in daily life. This response demonstrates that students have developed environmental awareness. These findings are following with references stating that dilemma story approaches can develop concern for the environment by making decisions based on scientific knowledge of the environment (Taylor & Taylor, 2012). The achievement of excellent levels in the affective aspect is demonstrated in the following interview transcript.

Researcher: Explain your responses about petroleum use such as gasoline that is done excessively considered harmful to the environment, but on the other hand needed for daily use?

Student 19: In my opinion, for now, we cannot escape 100% of the use of petroleum as an energy source, but we can minimize the use of petroleum. We must be wise in the use of petroleum and we must also think that the use of petroleum has a devastating impact on the environment and is a non-renewable energy. So, on the other hand we have to find new alternative energy sources to substitute petroleum.

Researcher: What energy sources can be used to substitute petroleum?

Student 19: A more environmentally friendly and easy to obtain energy source such as making biodiesel from vegetable and animal fats, bioethanol from plant fermentation.

(Student interview, December 11, 2019)

The above interview shows that student 19 has a strong interest in chemical issues related to petroleum use in daily life such as the use of gasoline in vehicles, meaning that the use of petroleum is difficult to eliminate. However, the student also argued that petroleum use needs to be followed by public awareness of its impact on the environment. Strong interest is also characterized by the student's solutions to reduce petroleum use by substituting alternative energy sources that are more environmentally friendly and easier to obtain, such as the use of bioethanol and biodiesel. This shows that environmental awareness in students has developed and that a dilemma story approach can develop concern for the environment by providing opportunities for making decisions based on scientific knowledge of the environment (Taylor & Taylor, 2012).

16.67%, or as many as 6 students, reached a good level in the affective aspect indicating that they have an interest in various chemical issues and can explain the impact of chemistry and its application in daily life as shown by the following field notes.

"During the learning process students expressed their opinions regarding the negative impacts of petroleum use such as gasoline that was done excessively. Students realize that if they want to travel a distance that is not too far away, it is best to use a bicycle or walk rather than on a motorcycle because the student realizes that the negative impact of vehicle fumes is not good for the environment and health." (Researcher's field notes, November 20, 2019)

The field notes indicate a change in the mindset of students in making decisions about using gasoline in daily life in response to knowing about the negative impacts of petroleum on the environment and on health. The change in mindset indicates that students have an interest in chemical issues related to petroleum and they can apply their understanding to issues in everyday life. This view is supported by Majid and Rohaeti (2018) who states that while contextual-based learning is effective in developing students' positive attitudes. The achievement of good levels in affective aspects is also shown in the following observation transcript.

Researcher: What causes acid rain?

Student 31: The result of vehicle and factory fumes, Miss.

Researcher: How to resolve with acid rain?

Student 25: It is recommended to make filtering on the chimney and using more environmentally friendly fuels, can also use electric energy in vehicles.

(Observation sheet, 27 November 2019)

The above responses show that the students related to the fact that vehicles and factory fumes cause acid rain. The students' interest in various chemical issues is characterized by their statements providing solutions to make filtering on factory chimneys and using more environmentally friendly fuels to reduce pollutant gases. The, students also provided solutions to utilize electric power to reduce pollutants produced from vehicles.

Based on the results of the chemical literacy test, 0% of students reached a moderate level in the affective aspect. However, during the learning process, some students scored at a moderate level as indicated by the following observations.

> *Researcher: What are the effects of acid rain?*
>
> *Student 21: It can cause corrosion to iron, and plants will wither.*
>
> *Researcher: Other than that?*
>
> *Student 6: Causes the fish in the river to die.*
>
> (Observation sheet, 27 November 2019)

Student 21 and 6 were only able to briefly explain the impact of acid rain on the environment, and they did not explain why it happens.

Based on the results of the chemical literacy test on the affective aspect, 0% of students reached a low and very low level indicating that all students show an interest in chemistry issues.

> *"Students show interest in chemical issues about petroleum. Besides, students can resolve the negative impacts of using petroleum with a proper understanding of chemistry."* (Observation sheet, 27 November 2019)

The results of the chemical literacy test on the affective aspect above, show that most students reached a very good level of interest in chemistry issues. The affective aspect of attitudes, interests, motivation, self-concept, and morals, plays an important role in learning chemistry (Rahayu, 2015), a view that is supported by Shwartz et al. (2006) who states that the affective aspect encourages someone who has a realistic view of chemistry and its applications.

4. Conclusions

The implementation dilemma stories integrated with a STEAM project was accomplished through five learning steps: 1) value reflection; 2) problem-solving; 3) project development to develop strategy and tactics; 4) monitoring and evaluation to develop simple and strategized explanations; and 5) transformation to conclude the learning process and reflect on changes in values, attitudes, and knowledge during the learning process. The research and consequent discussion suggest that the students' chemical literacy regarding was developed, particularly in general scientific ideas, characteristics of chemistry, chemistry in context, high-order learning skills, and the affective aspect.

Dilemma stories help students relate chemistry concepts and problems to their daily lives. Students had the opportunity develop creative and innovative solutions to a problem, presented in a dilemma story, by collaborating with their peers. The researchers integrated a suitable chemistry-based dilemma story with a STEAM project while empowering students and managing time resources. During the process, students started to challenge their critical and creative thinking within the existing learning environment. Teachers also learned to develop their competencies at being facilitators and agents of change, in addition to skills development in dealing with student differences. The overall result of the study showed the teacher can use the integration of dilemma stories into a STEAM project as an alternative to chemistry learning approaches that can develop students' chemical literacy. Further research needs to be carried out related to the implementation of dilemma stories integrated with a STEAM project to other chemistry learning topics.

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References

Chandrasegaran, A.L., Treagust, D.F., & Mocerino, M. (2008). An evaluation of a teaching intervention to promote students' ability to use multiple levels of representation when describing and explaining chemical reactions. *Research in Science Education*, 38(2), 237-248. https://doi.org/10.1007/s11165-007-9046-9

Chonkaew, P., Sukhummek, B., & Faikhamta, C. (2016). Development of analytical thinking ability and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (STEM education) in the study of stoichiometry. *Chemistry Education Research and Practice*, *17*(4), 842-861. https://doi.org/10.1039/C6RP00074F

Cigdemoglu, C., Arslan, H.O., & Cam, A. (2017). Argumentation to foster pre-service science teachers' knowledge, competency, and attitude on the domains of chemical literacy of acids and bases. *Chemistry Education Research and Practice*, 18(2), 288-303. https://doi.org/10.1039/C6RP00167J

Dewey, J. (1985). *Democracy and education: An introduction to the philosophy of education*. MacMillan.

Fessenden, R.J., & Fessenden, J.S. (1982). *Organic Chemistry*. PWS Publisher.

Gilbert, J., & Tragust, D. (2009). *Multiple Representations in Chemical Education*. Springer.

Gonzalez, H.B., & J.Kuenzi, J. (2012). Science, technology, engineering, and mathematics (STEM): A primer. *Congressional Research Service*, 1-15.

Guba, E.G., & Lincoln, Y. (1989). *Fourth Generation Evaluation*. SAGE Publications.

Hadinugrahaningsih, T., Rahmawati, Y., & Ridwan, A. (2017). *Developing 21st century skills in chemistry classrooms: Opportunities and challenges of STEAM integration*. 030008. https://doi.org/10.1063/1.4995107

Hofstein, A. (2015). The Development of High-Order Learning Skills in High School Chemistry Laboratory: "Skills for Life." In *Chemistry Education* (517-538). Wiley-VCH Verlag GmbH & Co. KGaA. https://doi.org/10.1002/9783527679300.ch21

IEA (2012). *PIRLS 2011 International Results in Reading*. International Association for the Evaluation of Educational Achievement (IEA).

Johnstone, A.H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7(2), 75-83. https://doi.org/10.1111/j.1365-2729.1991.tb00230.x

Miles, M., & Huberman, A. (1994). Qualitative data analysis: An expanded sourcebook. *Journal of Environmental Psychology*, 14(4), 336–337. https://doi.org/10.1016/S0272-4944(05)80231-2

National Research Council (2012). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Majid, A.N., & Rohaeti, E. (2018). The effect of context-based chemistry learning on student achievement and attitude. *American Journal of Educational Research*, 6(6), 836-839. https://doi.org/10.12691/education-6-6-37

OECD (2019). *PISA 2018 Results*. Organisation for Economic Cooperation and Development (OECD).

Papen, U. (2005). *Adult literacy as social practice: More than a skill* (1st ed.). Routledge.

Paul, R., & Elder, L. (2007). *Critical Thinking Competency Standards*. The Foundation for Critical Thinking.

Prastiwi, M.N.B., & Laksono, E.W. (2018). The ability of analytical thinking and chemistry literacy in high school students learning. *Journal of Physics: Conference Series*, 1097, 012061. https://doi.org/10.1088/1742-6596/1097/1/012061

Rahayu, S. (2015). Evaluating the affective dimension in chemistry education. In *Affective Dimensions in Chemistry Education* (29-49). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-45085-7_2

Rahmawati, Y., Ramadhani, S.F., & Afrizal (2020). Developing students' critical thinking: A steam project for chemistry learning. *Universal Journal of Educational Research*, 8(1), 72-82. https://doi.org/10.13189/ujer.2020.080108

Rahmawati, Y., Ridwan, A., Hadinugrahaningsih, T., & Soeprijanto (2019). Developing critical and creative thinking skills through STEAM integration in chemistry learning. *Journal of Physics: Conference Series*, 1156(1). https://doi.org/10.1088/1742-6596/1156/1/012033

Rahmawati, Y., Ridwan, A., Mardiah, A., & Afrizal (2020). Students' chemical literacy development through STEAM integrated with dilemmas stories on acid and base topics. *Journal of Physics: Conference Series*, 1521(4). https://doi.org/10.1088/1742-6596/1521/4/042076

Rahmawati, Y., Nurbaity, & Marheni (2014). Engaging Students in Social Emotional Learning : The Role of Dilemma Stories In Chemistry Learning. *Proceeding of International Conference On Research, Implementation And Education Of Mathematics And Sciences* (18-20).

Raub, L.A., Shukor, N.A., Arshad, M.Y., & Rosli, M.S. (2015). An integrated model to implement contextual learning with virtual learning environment for promoting higher order thinking skills in Malaysian secondary schools. *International Education Studies*, 8(13). https://doi.org/10.5539/ies.v8n13p41

Salam, F., Mailok, R., Ubaidullah, N., & Ahmad, U. (2016). The effect of project-based learning against students' engagement. *International Journal of Development Research*, 6(02), 6891-6895.

Settlemaier, E., Taylor, P.C., & Hill, J. (2010). Supporting teachers, challenging students: Socially responsible science for critical scientific literacy. *XIV IOSTE Symposium: Socio-Cultural and Human Values in Science and Technology Education*.

Shwartz, Y., Ben-Zvi, R., & Hofstein, A. (2006). The use of scientific literacy taxonomy for assessing the development of chemical literacy among high-school students. *Chemistry Education Research and Practice*, 7(4), 203-225. https://doi.org/10.1039/B6RP90011A

Sirhan, G. (2007). Learning Difficulties in Chemistry: An Overview. *Journal of Turkish Science Education,* 4(2), 2-20. Available at: http://www.tused.org

Taylor, E., & Taylor, P.C. (2012). Ethical dilemma story pedagogy: Engaging diverse learners in science education for sustainability. In Mansour, N., & Wegerif, R. (Eds.), *Science education for diversity in knowledge society*. Springer.

Taylor, E., Taylor, P.C., & Chow, M. (2013). Diverse, disengage, and reactive: A teacher's adaptation of ethical dilemma story pedagogy as a strategy to re-angage learners in education for sustainability. In Mansour, N., & Wegerif, R. (Eds.), *Science Education for Diversity. Cultural Studies of Sciense Education* (97-117). Springer.

Tsaparlis, G. (2000). The states-of-matter approach (soma) to introductory chemistry. *Chemistry Education Research and Practice*, 1(1), 161-168. https://doi.org/10.1039/a9rp90017a

Wurdinger, S., Haar, J., Hugg, R., & Bezon, J. (2007). A qualitative study using project-based learning in a mainstream middle school. *Improving Schools*, 10(2), 150-161. https://doi.org/10.1177/1365480207078048

Yakman, G., & Lee, H. (2012). Exploring the exemplary steam education in the U.S. as a practical educational framework for Korea. *Journal of The Korean Association For Science Education*, 32(6), 1072-1086. https://doi.org/10.14697/jkase.2012.32.6.1072

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