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Integrating Dilemma Stories into Chemistry Learning: Analyzing Students' Critical Thinking Skills

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Abstract

Critical thinking is a key competency for 21st-century students, essential for logical reasoning, decision-making, and academic success. However, studies indicate that Indonesian students often exhibit low levels of critical thinking. Chemistry, particularly topics like oxidation-reduction reactions, offers real-life applications, such as waste oil disposal, that can be leveraged to improve these skills. This study aims to analyze the effectiveness of integrating dilemma stories into project-based learning (PBL) to enhance students' critical thinking skills in the context of oxidation-reduction reactions. The study was conducted at SMAN 77 Jakarta with 36 students from Class X Mathematics and Natural Science 2. A qualitative approach was used, with data collected through observations, reflective journals, interviews, and critical thinking tests. The integration of dilemma stories in PBL was implemented through five stages: value reflection, problem-solving, project development, monitoring and evaluation, and transformation. The findings indicate significant improvements in students' critical thinking, creativity, collaboration, and problem-solving skills. Based on test results, students achieved level 3 (Acceptable) in critical thinking. The approach also enhanced their understanding of chemical concepts and awareness of addressing real-world problems. The integration of dilemma stories within PBL has proven effective in fostering critical thinking and other 21st-century skills in chemistry learning. This approach can serve as a model for innovative educational practices in STEM subjects.

Keywords: chemistry learning, critical thinking, dilemma stories, project-based learning

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1. Introduction

The development of the 21st-century requires students to have 4C competencies, critical thinking, communication, collaboration, and creativity. Critical thinking skills are one of the indicators of learning and innovation abilities which are one of the main groups in 21st-century skills. Critical thinking skills play an important role in honing logical thinking skills, decision-making, and academic success (Facione, 2020; Paul & Elder, 2021; Butler, 2012). So, we can decide whether the information obtained can be accepted or rejected (Haynes et al., 2016). Nowadays, critical thinking skills are the abilities needed by students to face changing circumstances or various challenges that occur in daily life.

The trends of students' critical thinking skills in Indonesia are generally low (Hidayati & Sinaga, 2019; Suparman et al., 2023), this is caused by the lack of student attention in learning, analyzing questions, and rarely making habits that encourage critical thinking skills (Hasmarani et al., 2019). Kawedhar et al. (2020) found that students often struggle with interpreting information by thinking critically. Similarly, Mardiah et al. (2022) reported that traditional teaching methods, which emphasize memorization over conceptual

understanding, fail to develop critical thinking skills effectively.

In some nations, the lack of critical thinking skills is caused by educational systems that do not facilitate students actively in discussions, debates, and assessing their thinking processes (Shaw et al., 2020). The weakness of critical thinking skills is also influenced by the habits of students who can only complete calculations without being able to interpret the answers (Priyadi et al., 2018). In addition, chemistry learning in schools generally focuses on memorizing concepts and formulas, so that students are only oriented towards the final results and grades (Farida & Muchlis, 2017).

The skills of asking questions, expressing opinions, seeking supporting evidence, evaluating information obtained, and daring to argue are essential components of critical thinking that students need (Sarican & Güneş, 2021). These abilities are crucial for aligning with 21st-century competencies, which include critical thinking, communication, collaboration, and creativity. Therefore, an education system oriented towards problem-solving, critical, creative, systematic, and logical thinking skills is necessary to prepare students for future challenges (Trilling & Fadel, 2009; Brookfield, 2012; Paul & Elder, 2021).

Chemistry learning in the 21st-century is expected to train students' critical thinking skills through learning activities by applying learning materials in everyday life. This is in line with Majid and Rohaeti (2018) who stated that the content of chemistry learning cannot be separated from our life. One of the chemistry learning materials that is closely related to life is oxidation-reduction. Although the material is very close, some students have difficulty understanding oxidation-reduction.

The results of the study showed that students had difficulty in learning oxidation-reduction reactions, especially in interpreting the concept in life. This is due to the learning approach that emphasizes mathematical calculations rather than understanding concepts and opportunities to develop thinking skills (Asniadin et al., 2022; Hidayat, 2022; Simamora, 2022).

The solution to overcome the problems above is to apply the learning approach that helps students build their critical thinking skills. One of the learning approaches that can attract students' interest in learning is the dilemmas stories approach. According to Taylor et al. (2013), the dilemma stories approach engages students by presenting real-life problems that require critical thinking and decision-making. The method not only enhances critical thinking skills but also increases students' motivation and participation in the learning process.

The dilemma stories approach fosters collaborative reflection, critical thinking, communication, and empathy (Taylor et al., 2013). It also enhances learning motivation, responsibility, curiosity, and the confidence to engage in argumentation (Elfrida et al., 2017). Studies indicate that employing dilemma stories can significantly improve students' critical thinking abilities.

Previous research found that project-based learning (PBL) can increase students' motivation to learn and enhance student's creativity, critical thinking, and problem-solving (Wan, et al., 2020). Additionally, project-based learning (PBL) has been shown to enhance students' comprehension of subject matter, problem-solving capabilities, critical thinking skills, and science process skills (Redhana, 2010; Özer & Özkan, 2012).

Based on the description above, integrating the dilemmas stories approach with the project-based learning model has the potential to develop students' critical thinking skills. This is because both approaches have a constructivist philosophical basis and are contextual-based learning, which promotes more meaningful learning. Contextual-based learning, in particular, encourages students to explore real-world situations, thereby stimulating the development of critical thinking skills (Raub et al., 2015). Based on this background, researchers are interested in

conducting research to determine students' critical thinking skills through the integration of dilemmas stories in project-based learning on oxidation-reduction reaction material.

2. Research Method

This study employed qualitative research with the subject 36 students from class X MIPA at SMAN 77 Jakarta. The instruments used in this study have been validated by five experts using the Likert scale to ensure content validity and consistency. The research procedure was carried out in three stages: initial, implementation, and final stages. The initial and implementation stage was designed to systematically guide students through reflection and problem-solving.

2.1. Initial Activity Stage

Activities carried out in the initial activity stage include: (1) Conducting preliminary studies in the form of observations aimed at determining the characteristics of students during the learning process; (2) Preparing research instruments, such as lesson plans, dilemma stories, student reflective journals, interview guidelines, critical thinking questions, and observation sheets; (3) Conducting assessments of the quality of the dilemma stories and validation of critical thinking questions validated by five experts, consists of three Chemistry Education Lecturers from Jakarta State University and two Chemistry Teachers from SMAN 77 Jakarta; (4) Making project designs.

2.2. Implementation Activity Stage

According to Werth (2017), learning activities utilizing the dilemmas stories approach involve the teacher reading a dilemma story, after which students debate how to resolve the dilemma question that was read. Every dilemma question includes a pause during which students are urged to consider how they might approach the subject on their own. After that, students are asked to justify and explain their choices. Following the period of individual reflection, group members continue to share ideas and during class discussions, solutions or final decisions are decided.

The implementation activity stage of combining project-based learning with the dilemmas stories approach makes use of the five learning phases proposed by Rahmawati et al. (2019), which are as follows: (1) Value Reflection: students consider the values in the given dilemma tale; (2) Problem-Solving: students are encouraged to concentrate on the story's issues and offer answers by developing projects; (3) Project Development: students create a waste processing project by planning a timeline; (4) Project Monitoring and Evaluation: instructors and students keep an eye on the progress of projects and carry our experiments; (5) Transformation: educators and learners assess the lessons learned and consider how.

2.3. Final Activity Stage

The final stage in this research focuses on the analysis of promoting incremental development of critical thinking skills. Activities carried out in the final activity stage include: (1) Processing data obtained from interview results, observation sheets, filling in critical thinking questions, and reflective journals; interviews were conducted to gather more in-depth information about students' responses to implementation dilemmas stories integrated project-based Learning and to observe the development of students' critical thinking skills. Reflective journals were used to find out students' reflections on the learning that has been carried out; (2) Analyzing data, which consists of data reduction, data presentation, and drawing conclusions; (3) Compiling the final research report.

3. Result and Discussion

The research was conducted at SMAN 77 Jakarta from January to March which was conducted during five meetings in the even semester of the 2023/2024 academic year. This study aims to determine the critical thinking skills of students through the integration of the dilemmas stories approach in project learning based learning on the material of reduction and oxidation reactions. The results of the research and discussion in this study are

divided into three; the assessment of the dilemma story, the application of the dilemmas stories approach in project-based learning, and the analysis of students' critical thinking skills.

3.1. Dilemma Story Quality Assessment

Dilemma stories are a genre of stories that contain dilemmas. Ideally, dilemma stories contain concepts that are relevant to students' real lives (Taylor et al., 2019). The assessment was carried out with the aim of testing the feasibility of the dilemma story that will be used in learning and to avoid errors in terms of material concepts, grammar, or the storyline presented. The assessment rubric consists of six assessment indicators: (1) The dilemma is in the story and is related to everyday life; (2) The story is in accordance with the truth of chemical concepts; (3) The story can motivate learning chemistry; (4) The story develops critical thinking skills; (5) The material, plot, and content of the story are interesting; (6) The story can be used in chemistry learning. Each indicator consists of four assessment scales; scale 1 (disagree), scale 2 (less agree), scale 3 (agree), and scale 4 (strongly agree).

The highest assessment result is in the indicator of the existence of a dilemma in the story and the connection of the story to everyday life with a score of 4.00. Overall, the average obtained from the assessment results was 3.50. This shows that the dilemma story presented is considered suitable for use in the learning process, but improvements are still needed in several indicators. There are comments and suggestions given by the validator regarding the concept of chemistry and the storyline of the dilemma that need to be clarified. The validator stated that *"The reactions that occur in oil during frying must be explained, including oxidation or reduction reactions"* (Chemistry lecturer comment 2, January 3, 2024). Validator also suggested to *"Try to make the storyline more appropriate, dilemma questions should be able to measure the direction of students' answers"* (Chemistry lecturer suggestion 1, January 3, 2024).

The dilemma story also received positive comments from validators who stated that *"The topic is in line with current conditions, so students can be more careful in buying food fried using used cooking oil"* (Chemistry lecturer comment 2, January 3, 2024). In addition, *"The story is interesting, can hone students' thinking skills, increase insight, and provide new experiences for students"* (Chemistry teacher comment 2, January 20, 2024).

Based on these comments, the dilemma story presented is able to hone students' critical thinking skills. The dilemma story presented still needs improvement, so improvements are made first before being given to students in order to improve the quality of the dilemma story.

3.2. Integration of Dilemmas Stories in Project-Based Learning

The integration of dilemmas stories in project-based learning uses five stages of learning proposed by Rahmawati et al. (2019); value reflection, problem-solving, project development, project monitoring and evaluation, and transformation. Learning activities are explained in the following discussion.

3.2.1.Value Reflection

Value reflection is the stage of reflecting on values in learning. Reflection in learning is needed for students to review what they have learned and to improve and expand their understanding (Chang, 2019). At this stage, the teacher reads a dilemma story in front of the class about chemical issues that occur in everyday life by involving students as the main characters in the story. At the end of each story, there is a dilemma that must be discussed together, and each group is given the opportunity to express their opinions.

"Students relate the contents of the dilemma story to real life. Students understand that the disposal of used cooking oil can cause environmental damage, so they provide opinions on utilizing the waste. Students know that the cause of physical and chemical changes in oil is due to the oxidation reaction that occurs, if used cooking oil is used

continuously it can have a bad impact on health" (Observation sheet, January 29, 2024).

Based on the observation result, students can apply chemical concepts of chemistry in life, attract the students' interest who want to learn the relationship between chemistry and phenomena in daily life, and help students to understand the materials through dilemma stories (Solikah et al., 2024). Students understand the impact caused by the use of used oil in the process of frying food and the negative impacts of disposing of doused oil waste that is disposed of carelessly. In addition, students gain a new understanding of the term oxidation which is one of the redox concepts through phenomena that occur in real life.

Contextual learning in the application of dilemma stories can stimulate students to reflect on the values of the learning provided. This is in line with the statement Priansa (2015) which states that the purpose of contextual learning is to build knowledge in students by connecting learning through their experiences in life. So, the learning that has been done by students will be meaningful (Majid & Rohaeti, 2018). The application of dilemma stories presents stories that can build students' concern for the environment and chemical knowledge that is useful for human life (Rahmawati et al., 2021).

3.2.2.Problem-Solving

At this stage, the teacher gives a problem and questions at the end of each story presented to students. Students are given the opportunity to identify problems in the story and provide solutions related to the problems given (Nguyen, 2017). After making solutions individually, students then discuss to exchange information and arguments with other members in their respective groups. During the discussion, all students are actively involved in conveying the results of their thoughts in group discussions. Some students have the same thoughts so the ideas that emerge are combined and used as solutions to the problems given. After conducting group discussions, students then hold class discussions to get one final solution. *"Students were very active in group and class discussions and provided one final solution by making a product from processed used cooking oil waste"* (Observation sheet, January 29, 2024).

Oxidation reaction in oil can change the structure of fatty acids in the oil into a new compound such as peroxide and aldehydes. These changes will have an impact on color, odor, and rancidity changes. So, through discussion activities, students are expected to be able to design an oil-based product by integrating their understanding of the oxidation-reduction concept. The results of the class discussion related to the solution to the problem in the story are presented in Table 1.

Table 1. Product Manufacturing Division

Group	Products Made
1	Soap
2	Soap
3	Aromatherapy candles
4	Soap
5	Aromatherapy candles
6	Aromatherapy candles

Based on the data, the problem-solving stage went well. Students were able to play an active role in group discussions and class discussions. Students were also able to solve various open-ended problems and apply their knowledge by working on a specific project (Abidin, 2023). Students solved the problem by providing one solution; reprocessing used oil waste into a new product. The findings showed that the application of dilemmas stories can develop problem-solving skills in students. This is in accordance with research conducted by Taylor et al. (2013) that the application of the dilemmas stories approach can increase student involvement in solving problems and making decisions through discussion activities.

3.2.3.Project Development

At this stage, the teacher informs the students about the activities to be carried out, which include preparing a schedule, determining tools and materials, clarifying and processing used oil, testing products, and presenting the

results of the activities that have been carried out. The stages in making a project plan are carried out collaboratively between the teacher and students. Table 2 shows the project activity schedule that has been agreed upon by the students.

Table 2. Project Activity Schedule

Date	Activity
February 5th	Scheduling and determining tools and materials
February 12th	Disposable oil purifier
February 19th	Waste oil processing
February 26th	Product testing and presentation of project results

Table 2 provides a detailed timeline of activities, the timeline aims to train students' discipline to act on time. After making a schedule of activities, the teacher gives students time to explore the planned activities to be carried out (Barak & Yuan, 2021). Furthermore, students discuss to determine the tools, materials, and method of manufacture that will be carried out.

Based on the findings, learning activities at the project stage development went quite well, all groups had completed the activity plans to be carried out. This stage provides an opportunity for students to develop critical thinking skills and creativity to increase student involvement in learning (Rahmawati et al., 2019).

3.2.4.Project Monitoring and Evaluation

At this stage, the teacher is assisted by observers to monitor the project work activities carried out by students and adjust them to the previously determined timeline. Monitoring activities are carried out in two meetings, while evaluation activities that include product testing and presentation of activity results are carried out in one meeting. The first monitoring is the activity of clarifying used oil which is carried out in two stages. In the first stage, students soak dried banana peels in used oil. In the second stage, students filter and observe the clarification results. The results of the first monitoring are presented in Table 3.

Clarification of used cooking oil using banana peel as an adsorbent is one of the efforts to improve the quality of oil. This is in accordance with the results of research by Nasir and Nurhaeni (2014) that banana peel can be used to adsorb impurities in cooking oil and banana peel activated charcoal can reduce the peroxide value of used cooking oil. The repeated heating process will trigger the oxidation process which produces peroxide compounds. The presence of peroxide compounds in oil is a sign of a decrease in oil quality (Aminah, 2010). The ability of banana peel-activated charcoal to adsorb impurities and reduce peroxide levels in oil is supported by the presence of flavonoids which are classified as antioxidants. The results of research by Purwaningsih et al. (2019) showed that the flavonoid content in banana peel extract can reduce the peroxide value in used cooking oil by 6.24%.

Table 3. First Monitoring Results

Group	Oil Usage	Color before clarification	Color after clarification
1	3 times	Chocolate	Slightly brownish
2	7 times	Dark chocolate	Chocolate
3	4 times	Chocolate	Slightly brownish
4	5 times	Chocolate	Slightly brownish
5	3 times	Chocolate	Slightly brownish
6	3 times	Chocolate	Slightly brownish

The second monitoring is the processing activity of used oil that has been clarified into soap products and aromatherapy candles. Based on the results of the observation, students were very enthusiastic about working on the project, working neatly, and carefully. This is in accordance with research conducted by Nguyen (2017) that project-based learning is very effective in building student involvement. The monitoring results show that each group has completed their respective projects according to the predetermined timeline.

In the next activity, students carry out the evaluation stage including the product trial stage to see the level of product success and the presentation stage to explain the results of the project that has been made. Product testing is carried out organoleptically. Organoleptic testing on aromatherapy candle products is carried out by smelling the odor produced, both before and after the candle is burned, also seen from the durability of the time given. In this phase, students are expected to be able to develop their critical thinking skills by integrating the concept of oxidation-reduction with the combustion process carried out in the organoleptic test.

Next, the evaluation stage is carried out by presenting the results of the project that has been carried out by each group. The presentation is carried out using poster media to develop student creativity. The purpose of the presentation is to test the level of understanding and how to convey information from students related to the activities that have been carried out. Through this activity, students can develop critical thinking skills, convey information, and communicate well (Nguyen, 2017). The points presented in the group presentation include the background of the project, project creation activities (planning, process, results obtained), and obstacles faced while working on the project.

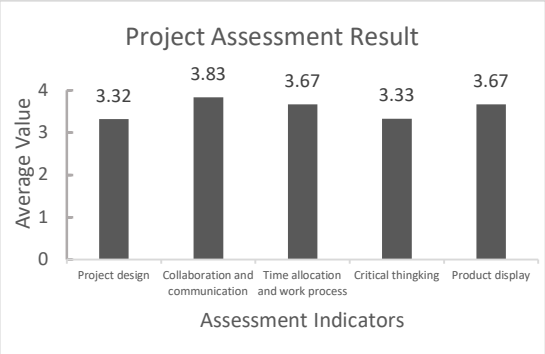

Figure 1. Project Assessment Results

Next, the product creation project that has been done by students is assessed. The assessment rubric includes: 1) project design, 2) collaboration and communication, 3) time allocation, 4) critical thinking process, and 5) product appearance.

Figure 1 shows that the results of the project that has been done by students get good grades. Students can complete the project according to the design that has been made, have a relationship with the concept of redox, and complete the project according to the predetermined schedule.

3.2.5.Transformation

The transformation stage consists of evaluating the learning experience and learning outcomes of students. Student learning outcomes are obtained through critical thinking skills tests and learning reflections are obtained by writing reflective journals. The following is one of the results of reflective journal from students, "*I think this learning is different from the others because usually, they give questions that go straight to the point, but this one gives a story first so it's not boring*" (Student reflective journal 19, March 4, 2024).

Dilemma stories are presented at the beginning of learning to increase motivation, interest in learning, and build student knowledge. This is in line with research conducted by Taylor et al. (2019) that the dilemmas stories approach as an alternative constructivist approach by applying a cognitive approach using dilemma stories to start building activeness, increasing learning abilities and interests in students. One of the students stated, *"In my opinion, this method requires students to think critically, creatively, and use reason"* (Student reflective journal 35, March 4, 2024). Similarly, another student stated, *"We are also trained to think broadly by discussing and exchanging information, establishing good communication with our friends. So that good collaboration can produce something good too"* (Student reflective journal 10, March 4, 2024).

The reflective journal shows that the integration of dilemma stories in project-based learning can train and develop students' critical and creative thinking skills. This is in line with research conducted by Elfrida et al. (2017) that the use of dilemma stories in learning can train students to think critically and creatively. The dilemma stories approach

can improve critical thinking skills because students are trained to make decisions based on the information and chemical concepts they have (Solikah et al., 2024). In addition, dilemma stories learning can also develop students' soft skills in collaborating with other students.

3.3. Analysis of Critical Thinking Skills in Students

The findings were categorized into five indicators of critical thinking: interpretation, analysis, evaluation, inference, and explanation. Each indicator was analyzed using both qualitative and quantitative evidence. Analysis of students' critical thinking skills is explained in the following discussion.

3.3.1. Interpretation

Figure 2 shows the achievement of students' critical thinking levels in the interpretation aspect obtained from the results of the critical thinking skills test.

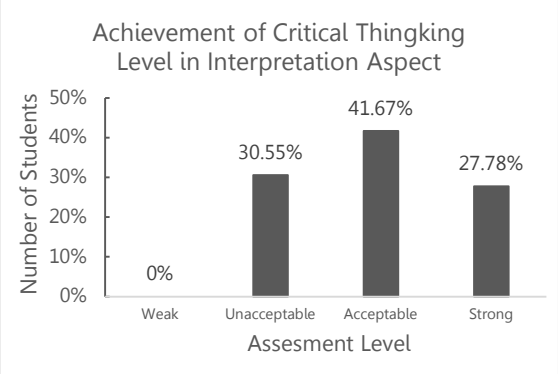

Figure 2. Histogram of Critical Thinking Level Achievement in the Interpretation Aspect

As many as 10 students (27.78%) achieved the highest level in the interpretation aspect of critical thinking skills, this achievement is supported by the following result of student interview.

"The problem of improper waste disposal and excessive use of used cooking oil can have adverse effects on health, because the oil has reacted and caused physical changes from heating for too long, such as an unpleasant odor and a change in color to black. The reaction that occurs is oxidation because there is oxygen binding due to heating and exposure to air" (Student 30, personal communication, February 19, 2024).

The interview results showed that students were able to interpret the problem. Students were able to explain physical changes and the negative impacts of using used oil and understand that in the oil frying process oxidation reactions occur. According to Nainggolan et al. (2016) if oil is heated and exposed to air, it will experience oxidation reactions that produce peroxide compounds, high peroxide numbers will indicate damage to the oil and can also cause poisoning for those who consume it.

In addition, Figure 2 also shows that as many as 15 students (41.67%) have reached level 3 in the interpretation aspect of critical thinking skills. This achievement is supported by the following result of the student reflective journal.

"Half-cell reaction:
Oxidation : $2Ca \rightarrow 2Ca^{2+} + 4e^{-}$
Reduction : $O_2 + 4e^{-} \rightarrow 2O^{2-}$
Reducing agent : *Calcium (Ca)*
Oxidizing agent : *Oxygen (O_2)*
Oxidizing agents undergo reduction and cause other substances to be oxidized. While reducing agents undergo oxidation and cause other substances to be reduced" (Student reflective journal 17, February 5, 2024).

The result of the journal shows that students not only provide answers that oxidizing agents are always reduced or vice versa, but also provide relevant explanations related to the questions asked. The level of oxidation in a redox reaction must be the same as the level of reduction; that is, the number of electrons lost by the reducing agent must be the same as the number of electrons received by the oxidizing agent (Overby & Chang, 2022)

3.3.2. Analysis

Figure 3 shows the achievement of critical thinking level in the analysis aspect. Based on the figure, 52.78% of students reached level 4 (Strong) in the critical thinking skills evaluation

aspect. This achievement is supported by the interview results as noted by the researcher, *"The H_2SO_4 solution in the battery is a strong electrolyte solution which will ionize so that redox reactions can take place by releasing and receiving electrons and ultimately producing electrical energy for the vehicle"* (Researcher's note, January 29, 2024).

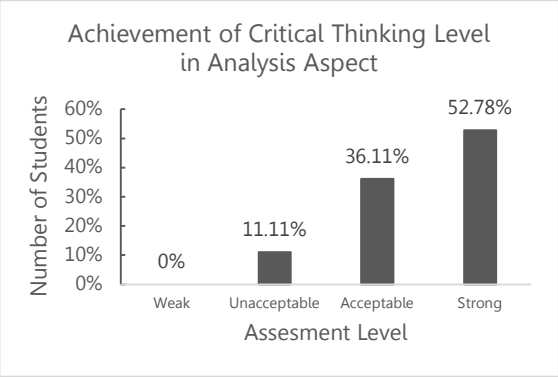

Figure 3. Histogram of Critical Thinking Level Achievement in the Analysis Aspect

The observation results show that students can analyze the working principle of the battery by connecting the concept of electrolyte material with the concept of redox material. The redox reaction that occurs in the work of the battery involves the transformation of electrons from substances that undergo oxidation to substances that undergo reduction, the transfer of electrons that occurs will obtain electromotive force which is used as a source of electrical energy in vehicles (Setiono, 2015). 13 students or 36.11% reached level 3 (Acceptable) in the analysis aspect, this achievement is supported by the interview results. One of the students stated *"Because used cooking oil has produced dangerous substances as a result of the oxidation reaction that occurs. If the substance enters the body too much, it can cause dangerous diseases"* (Student 24, personal communication, March 4, 2024).

The results of the interview show that students have provided relevant explanations regarding compounds that are harmful to the body resulting from oxidation reactions in used oil. The compounds produced from the oil oxidation process are the formation of peroxides and hydroperoxides. These compounds can cause symptoms of poisoning, irritation of the digestive tract, swelling of body organs, and can even cause death in the long term (Nasir & Nurhaeni, 2014).

Based on the analysis in Figure 3, the results of the study indicate that most students have critical thinking skills in the analysis aspect of 52.78%. This indicates that students' critical thinking skills have reached level 4 (Strong), meaning that most students can analyze by connecting concepts, accompanied by providing appropriate explanations. Students do not simply accept the information obtained, but analyze it first (Fisher, 2011).

3.3.3.Evaluation

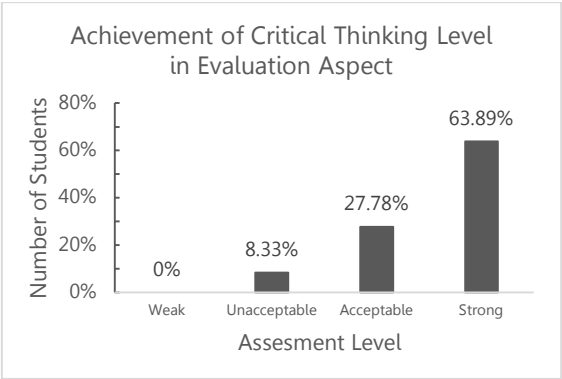

Figure 4. Histogram of Critical Thinking Level Achievement in the Evaluation Aspect

Figure 4 shows the evaluation aspect of students' critical thinking skills. Based on the data, the evaluation aspect shows that 63.89% or 23 students have reached level 4 (Strong), this achievement is supported by the following interview results.

"The disposal of waste will certainly cause pollution, whether it is disposed of on the ground or in water channels. The land will be damaged, living things in the soil will certainly die and the soil will become infertile, so plants can also die. If it is disposed of in water channels, it will certainly cause plaque or sediment that will clog the water channels" (Student 26, personal communication, February 5, 2024).

The results of the interview show that students have been able to assess the truth of a topic in detail, accompanied by providing appropriate explanations. Students evaluate the wrong waste disposal actions and also provide explanations regarding the impacts that will be caused if used oil waste is disposed of for free.

Based on this data, 27.78% of students have reached level 3 (Acceptable). This achievement is supported by the following student reflective journal.

"Not yet correct, the correct grouping is only in reaction C, while the other three reactions are wrong. Here is the correct answer"

a. $3NO_{2(g)} + H_2O_{(l)} \rightarrow 2HNO_{3(aq)} + NO_{(g)}$
+4 +5 +2

b. $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$
+1 +5 -2 +1 -1 +1 -1 +1 +5 -2

c. $2K_{(s)} + 2H_2O_{(l)} \rightarrow 2KOH_{(aq)} + H_{2(g)}$
0 +1 +1 0

d. $2H_2S_{(g)} + SO_{2(g)} \rightarrow 3S_{(s)} + 2H_2O_{(l)}$
-2 +4 0

(Student reflective journal 26, February 19, 2024).

The reflective journal shows that students have been able to determine the oxidation number of each element in each reaction first and then assess the credibility of a topic in general. So, it can be concluded that students' critical thinking skills in the evaluation aspect have reached level 4 (strong) with a percentage of 63.89% in other words, most students can evaluate a problem in detail, accompanied by providing appropriate explanations.

3.3.4.Inference (Draw a Conclusion)

Figure 5 shows the results of the inference aspect of critical thinking skills. Based on the results of the critical thinking skills test on the inference aspect, a percentage of 38,891% or 14 students have reached level 4 (Strong). This achievement is supported by the student reflective journal that *"Elements/atoms with lower electronegativity will have a positive oxidation number, while elements/atoms with higher electronegativity will have a negative oxidation number"* (Student reflective journal 14, February 12, 2024).

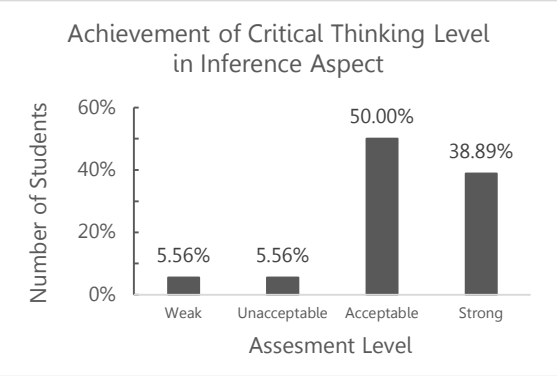

Figure 5. Histogram of Critical Thinking Level Achievement in the Inference Aspect

Based on the image, it can be concluded that students can identify the elements needed to draw a conclusion. This is indicated by students being able to determine the oxidation number of each element correctly and conclude the relationship between the principle of electronegativity in determining the oxidation number. This opinion follows Overby and Chang (2022), who explain that the rules for determining the oxidation number of an element in its compound are based on the principle of electronegativity.

Figure 5 also shows that 50.00% of students have reached level 3 (Acceptable). This achievement is supported by the student reflective journal that *"In conclusion, the oxidation number of metal elements is positive, while non-metals can be positive or negative"* (Student reflective journal 10, February 12, 2024).

The results of the reflective journal show that students only conclude that metal elements only have positive oxidation numbers, while non-metal elements can have positive or negative oxidation numbers, but do not link their understanding of oxidation numbers with electronegativity in determining the oxidation number of an element in its compound.

The result of the study shows that 50.00% of students have critical thinking skills that reach level 3 (Acceptable) in the inference aspect.

This means that most students can identify and select the elements needed to make a conclusion, explore information accompanied by relevant data, provide assumptions, and draw conclusions that can be accounted for (Subiantoro et al., 2010).

3.3.5.Explanation

The results of the explanation aspect can be seen in Figure 6.

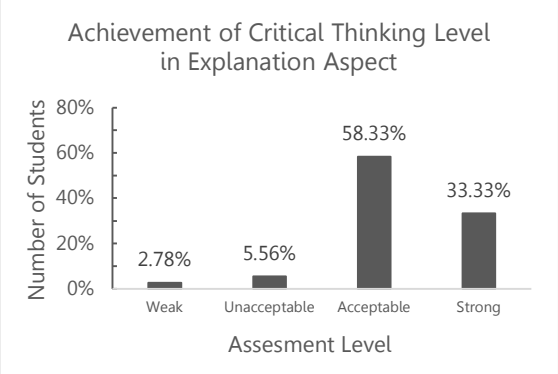

Figure 6. Histogram of Critical Thinking Level Achievement in the Explanation Aspect

The results show that 33.33% of students have reached level 4 (Strong), and this achievement is supported by the interview results. One of the students stated, *"The response must be advised properly, then explain about the bad effects on health if consuming food fried using used cooking oil, and we recommend replacing it with new oil after 3-4 uses to prioritize customer health"* (Student 30, personal communication, February 19, 2024).

The result of the interview shows that students have been able to put forward arguments that are in line with their understanding (Feldman, 2020). Students also put forward these arguments by providing reasons that are explained logically.

The results of the critical thinking skills test on the explanation aspect show that 58.33% of students have reached level 3 (Acceptable). This achievement is supported by the observation sheet that *"Students think that using banana peels to clarify used cooking oil is better than using charcoal because it has the same content; the presence of carbon elements in it"* (Observation sheet, February 5, 2024).

The explanation aspect can be analyzed with various instruments, one of which is by using an observation sheet. Based on the observation sheet, students can provide opinions and reasons that are quite relevant to the actions taken. In this explanatory aspect, students can put forward reasons regarding problems related to improving oil quality by using banana peels. This is in line with the results of research by Nasir and Nurhaeni (2014) that banana peels can be used to adsorb impurities in cooking oil and banana peel activated charcoal can reduce the peroxide number of used cooking oil.

Based on the analysis of students' critical thinking skills in Figure 6, the results of the study show that most students have critical thinking skills in the explanation aspect of 58.33%. This indicates that students' critical thinking skills have reached level 3 (Acceptable). In the explanation aspect, students can state a result, and provide reasons and arguments (Zhou et al., 2013).

Chemistry learning using the integration of dilemmas stories approach in project-based learning can be applied in the learning process. The learning outcomes obtained by teachers indicate that learning activities can be followed well and can support students' critical thinking skills to be better.

4. Conclusion

The integration of the dilemma story approach in project-based learning in chemistry learning shows that students have critical thinking skills at level 3 (Acceptable). Students can explain and interpret the role of redox reactions that occur in real life, analyze the causes of rust on iron, evaluate, express opinions, and make a conclusion related to oxidation-reduction reactions that occur simultaneously and the relationship of the electronegativity principle in determining oxidation numbers.

This study contributes to the development of innovative chemistry learning strategies by demonstrating the potential of dilemma stories and project-based learning to improve critical thinking and problem-solving skills. Future research should explore larger sample sizes and quantitative measurements to validate the generalizability of these findings.

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