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CRITICAL THINKING SKILLS OF CHEMISTRY STUDENTS BY INTEGRATING DESIGN THINKING WITH STEAM-PJBL

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Abstract

This project seeks to foster students' critical thinking abilities through the incorporation of Design Thinking with STEAM-PjBL in a chemistry redox process. 41 grade 10 students from a high school in Rangkasbitung, Banten, Indonesia participated in this study. Learning was facilitated by using a variety of online platforms, including Edmodo, Google Jamboard, and Zoom Meetings. Interviews, observations, journal reflection procedures, and researcher notes were used to gather qualitative data. The five steps of Design Thinking: empathize, define, ideate, prototype, and test, were used to facilitate learning (Plattner, 2010). Critical thinking skills were assessed through the indicators of Framing The Problem, Solution Finding, Self-Regulation, and Reflection, developed by Ucson and Rizona (2018). Based on the categories of Information Search, Creative Interpretation and Reasoning, Reflection, and Self-Regulation, the results demonstrate the development of students' critical thinking abilities to the advanced level. Design Thinking provides a way to more easily and actively create project-based solutions in solving contextual problems related to redox reaction of water pollution in the Ciujung River due to the use of detergent waste. Understanding the relationship of chemical concepts to daily life challenges the application of this approach. To challenge students' learning and help them acquire 21st-century abilities, STEAM-PjBL may be integrated with Design Thinking.

Keywords – Design thinking, STEAM-PjBL, Critical thinking.

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1. Introduction

The 21st century brings many challenges to society in all fields of endeavor. Increased mobility and the dissemination of information that can be obtained directly to each individual, have placed people in ignorance of contexts and situations that require analytical decision-making, and problem-solving skills (Luka, 2020). Therefore, to prepare people to face these challenges, effective education is needed so that new learning methods can be applied and students can develop 21st-century skills of creative and critical thinking, communication, and collaboration (Leifer & Steinert, 2011). The enhancement of student knowledge and ability calls for a pedagogy led by instructors who are prepared to handle complex problems (Dorst, 2011). A key element of academic and career success is the acquisition of critical thinking skills (Shaw, Liu, Gu, Kardonova, Chirikov, Li et al., 2020). In order to make judgments related to complex challenges, especially those pertaining to scientific learning, critical thinking plays a significant role in the process of assessing facts and ideas through logical reasoning and decision-making (Faridi, Tuli, Mantri, Singh & Gargrish, 2021).

Critical thinking is crucial for the study of science (Lee, 2018). Critical thinking can help identify important issues, recognize basic assumptions, evaluate evidence, and enable appropriate conclusions to be drawn. It is considered important as a component in active learning which aims to assess and self-regulate through interpretation, analysis, evaluation, results, and explanation of evidence conceptually, methodologically, and also through a contextual approach (Danczak, Thompson & Overton, 2017). According to Bloom's Taxonomy, critical thinking ability can be identified at the level of analysis, synthesis, and evaluation through reasonable reflective thinking and a focus on decision-making (Ennis, 1991). Assessing the reliability of a source, identifying conclusions, reasons, and assumptions, evaluating the quality of an argument, including the admissibility of the reasons, assumptions, and evidence, developing and maintaining a position on an issue, asking pertinent clarifying questions, planning experiments and evaluating experimental designs, defining terms in a way that fits the context, remaining open-minded, attempting to be well-informed, and concluding are all critical elements of decision-making (Ennis, 1993). These interrelated abilities can be a way to guide students' critical thinking because they can clarify, seek and assess a view, draw wise conclusions, integrate imaginatively, and achieve a stated purpose (Ennis, 1984). Critical thinking skills are often interpreted as thinking accurately, and systematically, based on the rules of logic and scientific reasoning (Leest & Wolbers, 2021).

Critical thinking skills are important in problem-solving because they require deep learning that enables complex problems to be solved (Varenina, Vecherinina, Shchedrina, Valiev & Islamov, 2021). Educators are therefore encouraged to plan learning opportunities that develop students' scientific abilities. Critical thinking skills, developed in chemistry lessons, will help students learn chemical concepts that are often considered difficult, especially in solving problems related to everyday life. Although the concept of chemistry is closely related to everyday life, students think chemistry is difficult to learn (Mondal & Chakraborty, 2013) because chemistry, such as studying matter and its changes, symbols, and modeling, is an abstract science, (Kohen, Herscovitz & Dori, 2020).

Redox reaction materials are a chemistry subject that students consider challenging despite their application in everyday life (Österlund, Berg & Ekborg, 2010). Reduction and oxidation reactions in daily life processes can be seen in photosynthesis, electrochemical cell reactions, and other bodily processes like Adenosine Triphosphate (ATP) creation (Brandriet & Bretz, 2014). However, when learning only employs the lecture technique, pupils can lose interest in chemistry. Students should be taught chemistry concepts using a constructivist learning approach that takes into account their prior knowledge, attitudes, skills, and experiences (Barke, Hazari & Yitbarek, 2009). In a constructivist learning context, critical thinking is a crucial competency that must be fostered and applied to solve complex problems (Uzumcu & Bay, 2020).

A Science Technology Engineering Arts and Mathematics (STEAM) approach can help develop students' critical thinking abilities as they learn chemistry. STEAM can make scientific lectures more engaging since it encourages students to express their creativity through the visual arts and can boost their drive to learn science (Conradty & Bogner, 2020). As part of the learning process, STEAM promotes students' problem-solving skills, innovative thinking, communication, and teamwork. Students will achieve more relevant learning outcomes through this approach because they can relate their learning to other fields of study and develop a deeper understanding of the materials they use in their projects (Herro, Quigley, Andrews & Delacruz, 2017).

A problem-solving method that can be applied in the real world, such as Design Thinking can be included in STEAM projects (Graham, 2020). When used in education, the Design Thinking framework can offer a unique approach because it not only offers STEAM-based learning content but also cross-disciplinary learning experiences through problem-solving related to real-world issues (Cook & Bush, 2018). The use of innovation in STEAM-based learning, particularly in the creation of student projects, can broaden the limits of disciplines and teach students to comprehend and be able to convey their knowledge while solving challenges (Rolling, 2016).

Design Thinking aims to enhance students' creativity (Carroll, Goldman, Britos, Koh, Royalty & Hornstein, 2010). It seeks to develop empathy, inspire ideas, and urge action to actively solve issues. Design Thinking is a multidisciplinary learning approach adapted from the corporate and educational spheres (Wrigley & Straker, 2017). It can be used to develop critical thinking skills and a deeper understanding of the relationships between the designs students develop to solve problems through the use of a reflective, creative approach. A variety of skills, including drawing, physical prototyping, brainstorming, aesthetics, focusing the mind as a user, and applying the design process, are used to reveal new learning that is focused on creating designs and new products (discovery, interpretation, ideas, experimentation, and evolution of design solutions). The outcomes of learning with this method include the development of student attitudes, behaviors, and thinking patterns as designers, as well as the growth of their capacity for dealing with difficulties. Design Thinking is essentially the process of coming up with ideas, assessing them, and choosing a course of action (Lin, Hong & Chai, 2020).

Design Thinking replaces direct instruction with phases of inquiry that transform the teacher into a facilitator to help students acquire skills such as creativity, communication, critical thinking, and cooperation. Design Thinking projects involve using a variety of processes to research and solve problems. Plattner's (2010) steps, described in an essay on the Design Thinking process, are shown in Figure 1.

Figure 1. Stages of Design Thinking

1) Empathize

The Empathize stage, which comes first in the Design Thinking process, strives to get to know the designer (user) and show concern (empathy) for their ability to produce innovative and meaningful solutions. Design Thinking methodology is human-centered and built on empathy. Empathy becomes a crucial part of the Design Thinking process because it can shed light on how people think and feel. The Empathize stage is characterized by user involvement, interaction with users, interviews with users, observations of user behavior in real-life circumstances, and internalization of the user experience.

2) Define

Define is the second step in the Design Thinking process. This process of assessing and synthesizing the results of one's empathy will display needs related to problems and understanding problems. This stage is intended to create serious issue statements and try to gain a thorough grasp of the user and the design environment. Because it frames the challenge, the defined mode is crucial to the design process.

3) Ideate

The third stage of Design Thinking, ideating, is all about coming up with new ideas. The purpose of ideate is to investigate a larger problem space for many different ideas as well as the differences among them. Ideate focuses mainly on idea generation, offering resources for creating prototypes and giving users creative solutions.

4) **Prototype**

Prototyping, which is the fourth step of the Design Thinking process, attempts to uncover ideas and solve problems, communicate, start conversations, test potential solutions, and oversee the process of solution creation. Prototypes can be created in a variety of ways such as in a tangible form that engages users. A low-resolution version of a prototype can take the form of a storyboard, a role-playing game, a tangible item, or a service.

5) **Test**

The Test Stage is the last step in the Design Thinking process which involves conducting tests, developing user experiences, and asking people to compare to improve ideas and prototypes and to better understand users (Point of View). This stage offers the chance to enhance the developed solutions because users' input on the prototypes can be requested.

The application of Design Thinking in STEAM-Project Based Learning is particularly beneficial because the process of resolving issues and identifying solutions enable students to engage in projects that pique their interest and are more relevant to their lives (Hölzle & Rhinow, 2019). Design Thinking can be applied as a theoretical and pedagogical approach to STEM learning (Carroll, 2015). It can increase the significance of STEAM-based learning because of its capacity to stimulate, promote, and produce answers to problems (Cook & Bush, 2018). A Design Thinking approach used in STEAM learning allows students to do more than merely comprehend the material and produce goods; instead, they can recognize, reflect on, and concentrate on the implementation stage of their creations. Both male and female students' academic performance is said to be greatly enhanced by the adoption of Design Thinking in STEM education (Simeon, Samsudin & Yakob, 2020). Female STEAM professionals develop their self-assurance, inventiveness, empathy, and social spirit through the Design Thinking methodology (Kijima, Yang-Yoshihara & Maekawa, 2021). The use of a Design Thinking strategy in STEAM project learning could aid future science and technology teachers to investigate and create projects connected to real situations (Lin, Wu, Hsu & Williams, 2021).

Through the Design Thinking process, students immediately understand the value of sketching, they try new ideas with a faster flow, and they can build their understanding and critical thinking (Roberts & Ritsos, 2020). Inquiry-based STEM projects increase student involvement in their learning and advance their critical thinking skills (Jeon, Kellogg, Khan & Tucker-Kellogg, 2021). The integration of STEAM with chemistry enables students to develop their critical thinking skills in chemistry by integrating chemical concepts, it empowers teachers and students and enhances time and resource management (Rahmawati, Ridwan, Hadinugrahaningsih & Soeprijanto, 2019). A STEAM approach can develop students' critical thinking skills, creativity, collaboration, communication skills, and awareness (5C) of environmental problems. It can also develop students' information, media, and technology skills such as operating various learning media platforms, using virtual classes and using various software to edit images or videos (Ridwan, Rahmawati, Mardiah & Rifai, 2020).

The Design Thinking STEAM project in this study is connected to chemistry and other academic fields. It is intended to assist students to develop their critical thinking skills when learning redox reaction chemistry so that they can realize suggested related projects. Therefore, the goal of this research was to enhance students' critical thinking abilities by incorporating Design Thinking and STEAM-PjBL into the study of chemistry by applying the research question:

"Can the integration of Design Thinking with STEAM-PjBL in chemistry develop students' critical thinking skills?"

2. Methodology

This study aimed to develop students' critical thinking skills in learning chemistry through the integration of Design Thinking with STEAM-Project Based Learning. The study used a qualitative research method, by exploring data in the form of images, text/writing, a representation of information, and personal interpretations through various data analysis procedures, all of which are considered important procedures (Creswell, 2009).

2.1. Research Design

This research took place at SMAN 1 Rangkasbitung, Indonesia, from November 2021 to July 2022. The research participants were students from 4 class of grade 10 science and mathematics classes. The target school was chosen because it could meet the research needs, such as the student's skills in mastering technology in learning so that they could work independently when using mixed or blended learning. The location of the school in a city allowed for many environmental problems to be identified as relevant student projects to be solved using chemistry concepts.

As illustrated in the accompanying Figure 2, the study was carried out in three stages: preliminary, implementation, and final.

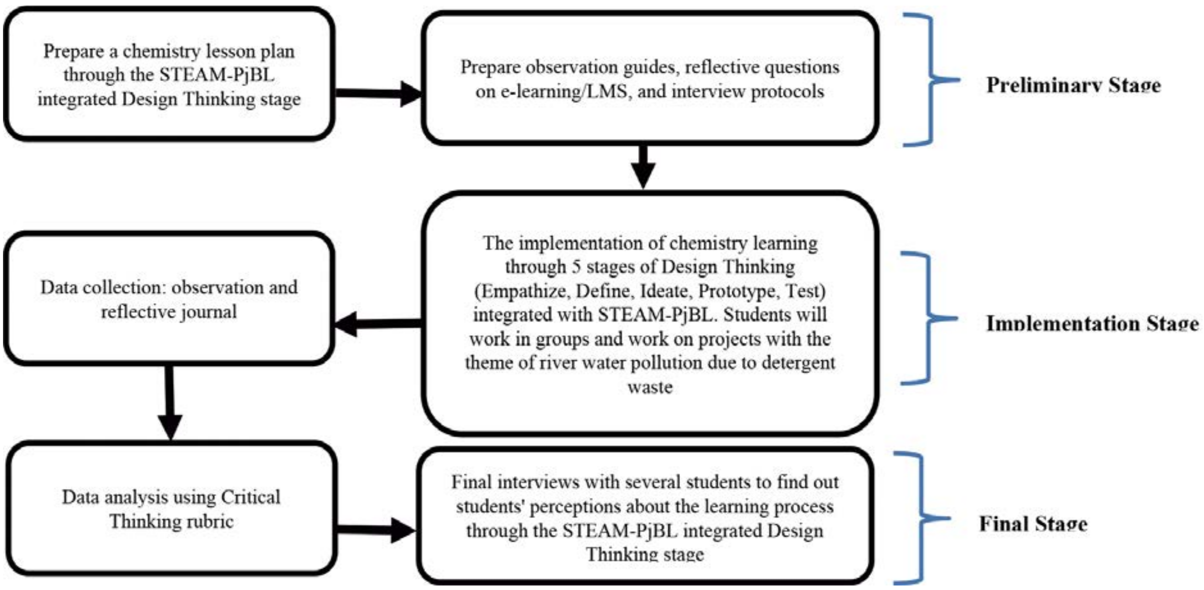


Figure 2. Research procedure flow

The preliminary stage of the research was carried out to create a design-thinking chemistry lesson plan with STEAM-PjBL. At this stage, the researcher also made an observation guide, developed reflective journal questions on an e-learning/Learning Management system (LMS), and created an interview protocol.

At the implementation stage, observations and reflective journals were used to explore data related to the critical thinking skills of students in chemistry learning. This was conducted through the Empathize, Define, Ideate, Prototype, and Test stages of the design thinking process (Plattner, 2010), which were integrated with STEAM-PjBL. During the implementation stage, 41 students were selected from different MIPA class X origins, namely Class of Sciences and Mathematics 1 until Sciences and Mathematics 4, each class is represented by 10-11 students. Students were divided into eight groups and each group worked on a project related to the use of detergents as an example of redox reactions in everyday life. The pollution of the Ciujung River, due to detergent waste around the students' homes, was the focus of the project. The five stages of Design Thinking integrated into STEAM-Project Based Learning are presented in Figure 3.

In the final stage, data analysis was carried out from observations and reflective journal results using critical thinking rubrics. In addition, several selected students were interviewed to obtain a more detailed description of their ideas/responses/comments related to STEAM-PjBL learning through the Design Thinking stages.

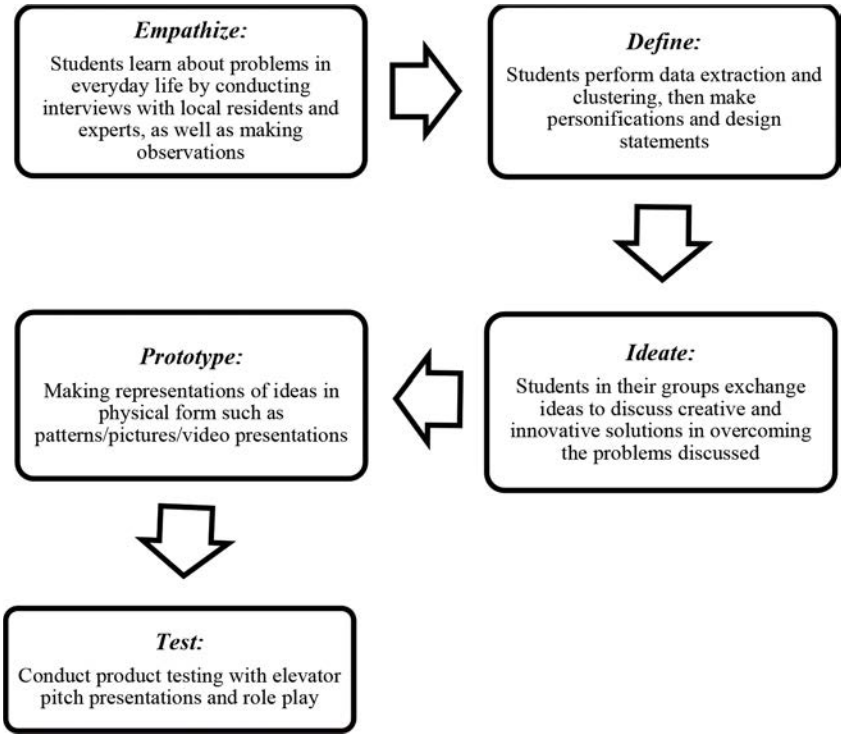


Figure 3. Five stages of Design Thinking integrated into STEAM-PjBL

2.2. Data Collection Techniques and Procedures

Primary data from students and secondary data from books, papers, and other digital references served as the study's data sources (e-books). Observation sheets and reflective diaries were utilized as the tools and procedures for data collecting in this study, which was combined with STEAM-PjBL and the Design Thinking stage of learning, which includes the Empathize, Define, Ideate, Prototype, and Test stages. Data analysis and interviews were conducted in the final phase.

2.2.1. Observation

To better understand the learning environment in the classroom and the student's development of critical thinking abilities, observations were used. Observers aided researchers in their observations during the learning process to guarantee that learning was implemented by the Design Thinking process.

2.2.2. Reflective Journal

After each class meeting, the students wrote in their reflective diaries. Data from student perspectives on the degree of engagement and challenges faced during the use of STEAM-PjBL integrated Design Thinking was gathered using reflective journals. Questions used in reflective diaries included the following:

> *What skills do you feel developed after participating in the prototyping activities, discussions at the zoom meeting, and role play today? Give an example.*

2.2.3. Interviews

Interviews with instructors and students were performed using a semi-structured format so that any further questions or research could delve deeper into the respondents' perspectives (Pratt & Yezierski, 2018). The purpose of the teacher interview was to discover how teachers typically teach chemistry, to identify any issues that arose, and to assess the student's critical thinking abilities. Questions related to the learning process, such as communication and group collaboration to solve problems in Design Thinking through STEAM-PjBL, aimed to gather information about the student's perception of the learning and to observe the development of their critical thinking skills. Below is an example of an interview question posed to the students:

> *What do you think about the empathy, define, ideate, prototyping, test, and discussion activities that have been carried out on your understanding of chemistry?*

2.2.4. Researcher Notes

The purpose of the researcher's notes was to track how pupils behaved when the STEAM-PjBL integrated Design Thinking method was put into practice in the classroom. Additionally, the instructor could provide evaluations or remarks in the notes that were hidden from observers.

2.3. Data Analysis Procedure and Validity Check

This study used three stages of a qualitative data analysis technique which include data condensation/ reduction, data display, and conclusion/verification (Miles, Huberman & Saldana, 2014). Data collection through observation, reflective journaling, and interviews is a continual process that results in data condensation/reduction and is accomplished by choosing just those data that are relevant to the student's critical thinking abilities. At the data display stage, the reduced data was presented as a matrix or coding based on indicators from the critical thinking rubric consisting of Framing The Problem (understanding the problem), Solution Finding (Developing strategies, solving problems, and Evaluation), Self-Regulation and Reflection (Reflection, Planning, mindset), each of which has a scale of 1 (Novice), 2 (basic), 3 (Proficient), and 4, and each of which has a scale of 1 (Novice) (Advanced) (Ucson & Rizona, 2018).

To check the validity of the data, credibility criteria were used to test internal validity and trustworthiness. These criteria are shaped by prolonged involvement, continuous observation, progressive subjectivity, and member examination (Huebner & Betts, 1999). Prolonged involvement was carried out during the research to understand the research context, and explore cases/events during the learning process. Additionally, throughout multiple learning meetings, the study situation and participant engagement in the STEAM-PjBL integrated Design Thinking stage were thoroughly explained. By involving researchers and observers directly, continuous observations were carried out to explore various phenomena that occurred during the learning process. Based on the traits of the student's critical thinking skills evaluation, progressive subjectivity was used to track the study's outcomes with all learning notes from students, teachers, and also researchers. To assure the accuracy of the data collected from the participants, member checks were conducted. For reasons of privacy, all information collected in the form of physical copies, digital copies, and interview transcripts is confidential.

3. Result and Discussion

3.1. Overview of Research Background

The implementation of this research began in January 2022 with initial observations and interviews with class X chemistry teachers. The research participants in this study were class X chemistry teachers and 41 students (8 groups) in class X Mipa SMAN 1 Rangkasbitung. During February-March 2022, 6 online meetings were held to learn Design Thinking related to the redox reaction chemistry lessons. Data were collected through observations at each Design Thinking meeting, reflective journals on google forms, online interviews, and tests of chemical understanding according to proposed solutions.

3.2. Critical Thinking Skills

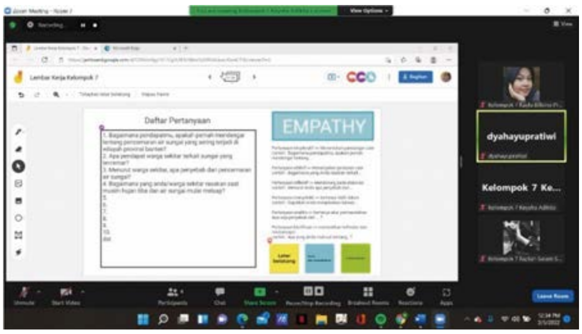
According to research, critical thinking abilities can be developed through the categories of information search, creative interpretation and reasoning, reflection, and self-regulation at the Empathize, Define, Ideate, Prototype, and Test stages of the Design Thinking stage, which is integrated with STEAM-PjBL.

3.2.1. Information Search

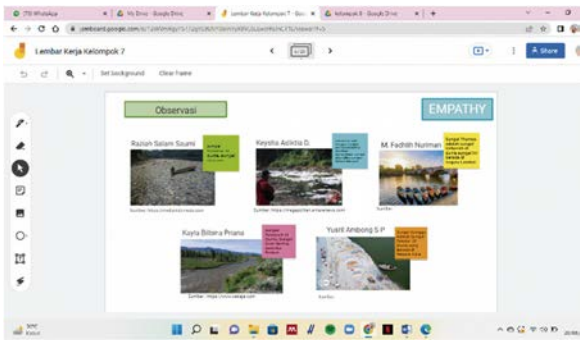
At the first meeting during the Empathize stage, students compiled interview questions to obtain data on community needs related to the relevant river water pollution. Each research group wrote draft questions on an electronic worksheet (google jamboard) which they then completed according to the creativity of each group. In the early stages of Design Thinking, students were assigned to look for information related to problems regarding the Ciujung River water pollution due to detergent waste as an application of the chemical concept of redox reactions to problems/events in daily life.

This skill category was generated from four aspects of the assessment; Framing the Investigation, Questioning, Information Gathering, and Source Evaluation. The Information Search category was obtained from observational data, reflective journals, researcher notes, and interviews with students who followed the stages of learning chemistry with Design Thinking. The data were adjusted to the critical thinking assessment rubric developed by Ucson & Rizona (2018), in the Framing The Problem section (Understanding the problem).

Overall, students' information search skills were generated from the Empathize, Define, and Ideate stages. At the Empathize stage, students sought information through sources and indirect observations via the internet. In the Define stage, the involvement of the information search process was evident when making personifications and design statements to determine a focus problem. At the Ideate stage, the involvement of information seeking was demonstrated during brainstorming ideas. The involvement of information seeking in Design Thinking activities in the Empathize, Define and Ideate stages are presented in the following Figures 4.a until 4.d below.

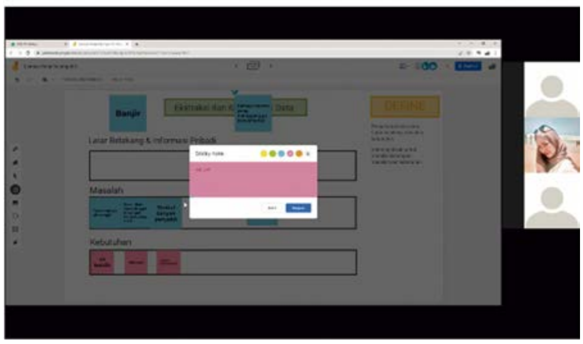


a)



b)

c)



d)

Figure 4. a) Activities for compiling interview questions. b) Display of observation results.
c) Interview activities. d) Data extraction and clustering activities

The pictures above show that the information search process is an important first step in solving a problem, in this case regarding pollution of Ciujung river water related to the chemical concept of redox reactions. At this stage, students were directly involved in solving contextual problems in their environment, related to chemical concepts, by compiling a list of interview questions to explore information from resource persons provided by the researcher. Students' skills in finding this information became one part of the assessment of critical thinking skills.

The research revealed that students were at the advanced level when it came to framing the investigation. The students could describe how the limitations of an investigation can affect the results and they could create strategies to get rid of biases connected to the issue being investigated. This is shown through the following observation notes.

> *Students began to find out and discuss the existing problems by making a list of questions according to the theme of pollution in the Ciujung river due to detergent waste (Observation, 5 February 2022)*

In the Questioning aspect, students were able to formulate and refine thought-provoking inquiry questions at the advanced level, carefully expressing them to influence the depth, quality, and value of the information obtained through the investigation. This is demonstrated through the following researcher notes.

> *Student 3: "at this meeting, I learned to formulate interview questions, but there were still problems writing on the google jamboard due to signal interference. Overall, I feel that I have gained new knowledge and have come to know about Design Thinking"*
>
> *(Researcher notes, 5 February 2022)*

Information Search skills were needed when conducting interviews and observations. The findings regarding the development of Information Search skills in the questioning aspect during the Empathize stage at the advanced level are shown by the reflective results of the following journal.

> *In this activity, we have to be braver when talking to resource persons, so before that, we discuss it first with our group mates so that when we ask questions everything goes smoothly*
>
> *(Journal Reflective, 14 February 2022)*

The Information Gathering aspect shows that students achieved the Advanced/Proficient level with the ability to collect information from various relevant, timely, and credible sources, using various collection methods; and deliberately seeking multiple perspectives or information that conflict with one's own beliefs, values, and perspectives. This is shown through the following observations.

> *Students seek information related to river water pollution problems and make observations about river water via the internet. Students also collect information related to problems that occur from several sources that have been provided by researchers. The resource persons are residents around the Ciujung river*
>
> *(Observation, 10 February 2022)*

Information search skills were also found at the Ideate stage of the Design Thinking process. During this stage, the students determined group ideas that came from the group brainstorming. Aspects of information gathering found in students were rated at the Advanced/Proficient level. This is shown through the following reflective journal results.

> *Student 26: "Provide ideas to solve problems. However, it can be overcome by seeking more ideas from various sources"*
>
> *(Journal Reflective, 2 March 2022)*

At the Source Evaluation stage, students scored at the Advanced level demonstrating the ability to synthesize various aspects of a source. Assessment of this aspect was conducted in the Empathize (interview and observation session) and Define stages. At the Define stage, students determined the personification and design statement that identified the focus of the problem from the results of data extraction and clustering. The findings of the assessment of this aspect are shown in the following observations.

Students choose and write down the results of their observations on an electronic worksheet (google jamboard). Each student shows different and varied references so that comparisons can be made between the results of one observation and another.

(Observation, 10 February 2022)

Students filter and select data to be loaded as a focus of problems whose solutions will be determined in the personification and design statement section of the Google Jamboard. Students in their groups discuss the results of the summary and additional information that has been obtained.

(Observation, 17 February 2022)

Based on some of the findings above, it can be concluded that the students' information-searching skills were developed to an advanced level. The information search category highlighted the development of critical thinking skills where the students conducted investigations, asked questions, and collected information related to the issues raised. However, students still needed assistance to find valid and reliable information so that they could select and filter information more quickly and easily. Through the activities in the design thinking stage, learning becomes more meaningful because students are actively involved and use critical thinking to find relevant information(Callahan, 2019). Learning carried out during the design thinking stage helps students develop their critical thinking skills by searching for information to solve problems.

3.2.2. Creative Interpretation and Reasoning

The Problem-Solving step is the next category in the Critical Thinking skill assessment which follows the Design Thinking stage beginning with the phases of Empathize, Define, Ideate, Prototype, and Test. To help students better grasp how to solve issues, each phase in the problem-solving process has a specific purpose.

Based on the findings from the Problem-Solving steps category, students were shown to be at level 4 (Capestone) which is characterized by the ability to create logical, efficient, and well-defined sequences of steps or instructions to solve problems or achieve goals.

Students describe their proposed ideas on an electronic worksheet (google jamboard) and produce group ideas as ideas to solve the problems discussed. Students use the internet, mass media, and social media to find references for product ideas that can be proposed. Students use various online/offline platforms to create prototype videos, as well as design drawings of proposed products. Several groups of students created WhatsApp groups containing small groups to make it easier for them to discuss doing all assignments.

(Observation, 24 February 2022)

Researcher: How is the ability to solve problems related to chemical concepts, especially those related to the theme of water pollution in the Ciujung River due to detergent waste?

Student 5: The problem-solving process is more structured because you look at the problem and then look for a solution

(Interviews, 2 April 2022)

Students' Interpretation and Creative Reasoning skills for the aspect of Meaning-making show that students are at the Advanced/Proficient level which is characterized by their ability to formulate logical and valid conclusions from information, analyze patterns to make meaning from all information, and consider several explanations before formulating conclusions by looking at different perspectives. These qualities are found at the Define stage and Ideate stages, in which students were asked to process data and provide ideas to determine a focus problem for which the solution will be found. The findings for this aspect of Meaning (Meaning-making) are shown in the results of the researcher's notes below.

Student 5: today was fun and more relaxed, it was fun when putting together the Jamboards because you can do it according to our creativity

(Researcher's notes, 17 February 2022)

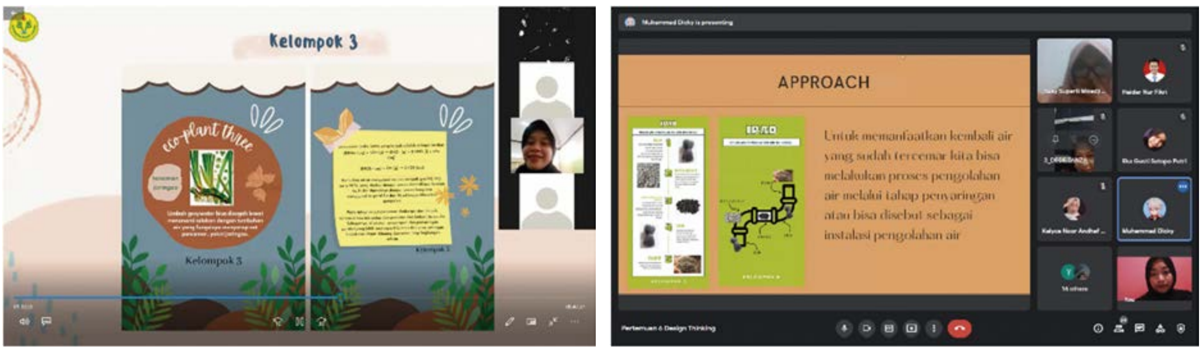
It may be inferred from some of the data above that students' interpretations and creative reasoning abilities developed to the proficient level in meaning-making and the advanced level in the organization. This demonstrated a development in students' Critical Thinking skills. It should be noted that for the aspect of Meaning-making, students still need to be guided to make it easier to reason and risk interpreting the results of their thoughts. In the findings related to Creative Interpretation and Reasoning, most of the students were able to demonstrate appropriate reasoning in explaining the reasons why detergent waste is harmful to the environment and is associated with the chemical concept of redox reactions. While they were not able to show detailed concepts, students understood the relationship between chemical concepts and everyday life. This shows the progress of students' thinking in recognizing the application of chemical concepts after going through the STEAM-PjBL integrated Design Thinking stage on the application of the chemical concept of redox reactions. The role of this problem-based context in everyday life is important for the progress of chemistry learning that studies concepts and their real-world applications (Domenici, 2022).

Because it requires higher-order thinking abilities such as observation, problem-solving analysis, and communication, as well as thinking abilities that are part of the scientific process, the process of solving problems through creative interpretation and reasoning is one of the categories in the development of critical thinking skills (Yildiz & Yildiz, 2021). However, these skills in Creative Interpretation and Reasoning still need to be taught so that students can be more critical in selecting and processing information, and more precise in producing conclusions with creative ideas. The results of several assignments at the Design Thinking stage, show that students can complete assignments competently although they need to be more daring in interpreting their ideas. The creative thinking process at the Design Thinking stage can become a forum for students to express, and dare to express, ideas to develop scientific process skills (Ozdemir & Dikici, 2017).

3.2.3. Reflection and Self Regulation

The category of Reflection and Self-Regulation is determined by taking into account the impact of learning chemistry through the Design Thinking stage on students thinking abilities and in developing skills and attitudes. This skill category was identified in the Define, Ideate, Prototype, and Test stages through observation, reflective journals, researchers' diaries, and interviews with participants, then adjusted to the Critical Thinking assessment rubric.

The three aspects, Reflection, Planning, and Mindset, become the assessment of Reflection and Self-Regulation. Through the Reflection aspect, students were assessed based on the feedback obtained from the learning outcomes and during the learning process. In the Planning aspect, students were assessed based on their critical thinking skills in determining a decision to achieve a goal. Whereas in the Mindset aspect, students were assessed based on the development of student's mindsets develop to be more active and able to show abilities that have never been honed before or that already exist but were considered undeveloped. Examples of activities that show the category of Reflection and Self-Regulation are found in the Prototype activity shown in the following Figures 5.a and 5.b below.



a) b)

Figure 5. a) Prototype presentation. b) Elevator pitch presentation

The picture above shows a reflection activity for students who can think critically in presenting and responding to the displayed designs. Self-regulation also seems to have developed in students who tried to receive input/suggestions from their friends regarding the improvement of their product designs, so that during the elevator pitch presentation session students were ready to present their proposed products better. Based on research findings on the student aspect of Reflection, students were at the Advanced level which is characterized by the ability to analyze patterns and trends in their thinking process, evaluate the results of thinking, reasoning, and critical thinking disposition during the process, and seek and act on feedback from peers, teachers, and experts for improvement. This assessment category was identified when students begin to develop group proposal ideas at the Ideate stage, when making product designs at the Prototype stage, and when students presented the elevator pitch and role-play at the Test stage. This is shown in the results of the journal reflection below.

Student 3: The skills that I have developed after participating in prototyping activities and discussions at zoom meetings, for example, are increasingly able to make graphic designs and discussion skills, and communication skills.

Student 5: We become more creative, I also become smarter at editing PowerPoint like that. When zoomed in today it was very, very fun and cool. In the role-playing game earlier, I was able to be more courageous to express opinions spontaneously. I also learned to argue a little earlier.

(Journal Reflective, 25 March 2022)

At the Planning aspect, students' Reflection and Self-Regulation abilities were demonstrated at the Advanced level, characterized by analyzing previous patterns and performance to set new goals in critical thinking, revising goals in response to ongoing reflection, and showing another possibility. This assessment category was identified when students began to produce product designs at the Prototype stage, as well as when students present their elevator pitches and role play at the Test stage. This is shown in the results of observations, researchers' diaries, and journal reflections.

Students can receive all responses and explain things that are still being asked by the audience.

(Observation, 23 March 2022)

Reflection and Self-Regulatory Ability of students assessed on the Mindset aspect show that students were at the Advanced level, characterized by the improvement of their areas of weakness by proactively implementing effective strategies to improve mindset development. These assessment criteria were found when students began extracting data at the Define stage when compiling group proposals at the Ideate stage, when making product designs at the Prototype stage, and when students presented the elevator pitch and role-play at the Test stage. This is shown in the results of the following interviews.

Researcher: How is your understanding of science, technology, engineering, art, and mathematics, in chemistry learning after participating in virtual learning with the Design Thinking method?

Student 39: So you understand better that chemistry, especially redox reactions, is close to technology. Have never experienced multidisciplinary learning.

(Interviews, 2 April 2022)

Based on the results of all the above findings, the student's self-reflection and self-regulation abilities were demonstrated to have evolved to the Advanced level. While this demonstrates that the participants' critical thinking abilities improved, students still needed help to be more precise in relating the proposed ideas to the chemical concepts being studied. The findings indicate that students can analyze critical thinking processes, and can act on the feedback they receive during the learning process based on the Reflection and Self-Regulation category. This assessment category was identified when students begin to collaborate on group proposal ideas at the Ideate stage, when making product designs at the Prototype stage according to the proposed idea, and when students present the elevator pitch and role-play at the Test stage.

Chemistry learning using the integration of Design Thinking is proven to develop students' critical thinking skills through Self-Reflection and Regulation. Through self-regulation, students can develop their scientific thinking skills (So, Chen & Wan, 2019). Because all stages of Design Thinking require collaboration and teamwork, self-reflection and regulation are essential learner attributes. A focus on discussions in team collaborations has been proven to develop critical thinking skills in the context of online learning situations (Cortázar, Nussbaum, Harcha, Alvares, López, Goñi et al., 2021).

The learning that was achieved at each stage of Design Thinking provided students with new experiences in carrying out chemistry learning. However, some students faced challenges in adapting to learning patterns that required them to think more critically and make decisions in a short time. This is the challenge of project-based learning that involves high critical thinking skills (Bağ & Gürsoy, 2021). The stages in Design Thinking provide a way for students to more easily create project-based solutions to problems through active engagement (Balakrishnan, 2021).

4. Conclusions

This study revealed how the integration of Design Thinking with STEAM-PjBL could improve students' critical thinking skills, in learning chemistry related to problems in everyday life. Critical thinking development was assessed through the Empathize, Define, Ideate, Prototype, and Test stages in the Design Thinking process which was integrated with STEAM-PjBL. Online instruction was implemented by involving students in problem-solving activities.

Considering the findings of the analysis of observational data, reflective journals, researchers' diaries, and interviews with students, the student's Critical Thinking skill was found in developed and obtained in 3 categories consisting of Information Search (Advanced level on aspects of Framing the Investigation, Questioning, Information Gathering, and Source Evaluation); Creative Interpretation and Reasoning (Advanced level in the Organization aspect, and Proficient level in Meaning-making); and Self-Reflection and Regulation (Advanced level in aspects of reflection, planning, and mindset). The learner may apply the chemical idea of redox reactions to real-world issues by combining Design Thinking with STEAM-Project Based Learning. In this case, the problem raised was the pollution of Ciujung River water due to detergent waste as a problem from the application of the chemical concept of redox reactions in daily life.

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The authors declare there are no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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