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Improving Students' Critical Thinking Ability Through a Project Based Learning Model on Basic Laws of Chemistry Concepts

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Abstract

This descriptive research aims to provide an overview of critical thinking ability (CTA) through the implementation of the Project-Based Learning model. The description is carried out based on the categorization of the normalized gain results according to Meltzser from the CTA aspect, namely interpretation, analysis, inference, deduction and evaluation abilities. The research subjects were Class XE1 of SMAN 1 Gowa with 35 students. Data collection on critical thinking skills using essay tests for basic laws of chemistry. From the research data, the N Gain Score value for all indicators of critical thinking skills is in the medium category. The N Gain Score value for the critical thinking skills indicator, namely interpretation skills is 74%, analysis skills is 56%, inference skills is 67%, deduction skills is 55%, and evaluation skills is 48$. With this increase it can be concluded that the Project-Based Learning model is able to improve skills students' critical thinking on basic laws of chemistry.

Keywords: *Critical Thinking Skills, Project-Based Learning, Basic Laws of Chemistry.*

Introduction

Critical thinking skills are considered very important in the 21st century to overcome the complexity of an ever-changing world (Khalid et al., 2021). These skills include problem solving, creative thinking, innovation, critical perspective, effective communication, and literacy in various forms, including media and information and communication technology (Koehorst et al., 2021). The need for these skills is emphasized in various educational settings, with the aim of preparing individuals to be able to thrive in a technologically advanced global society. As countries around the world strive to adapt to economic competition and technological advances, the development of 21st century skills has become an important aspect of education (Xu & Zhou, 2022).

Critical thinking ability are very important in chemistry education because they help students understand chemistry subjects in depth and prepare them to face complex global challenges (Szozda et al., 2022). Additionally, these skills enable students to critically analyze scientific data, models, and real-world problems. By thinking critically, educators try to show the relevance of chemistry to other fields and equip students with the skills to understand sustainability and global issues well (Mahaffy et al., 2019).

Including socio-scientific issues in chemistry education can also improve critical thinking skills, as it encourages students to argue, make decisions, and analyze information critically (López-Fernández et al., 2022). Efforts to improve critical thinking skills among chemistry students have been emphasized, especially in project-based learning environments (Ijirana et al., 2022), as chemistry education faces various challenges that affect the learning process.

Research shows that there are several challenges that need to be overcome to improve the quality of chemistry learning. One of them is the use of conventional learning methods which are often considered ineffective because they tend to produce passive learning and limited retention of information by students. Adopting more interactive methods such as direct learning, cooperative learning, and problem-based learning can increase student understanding and engagement (Ho, 2019; MacDonald et al., 2022).

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Another challenge comes from the students' diverse backgrounds and the perception that chemistry concepts are difficult to understand, including the basic laws of chemistry. This is caused by several factors, such as the abstract nature of chemical concepts which require in-depth understanding. In addition, some students may experience misconceptions in understanding the basic legal concepts of chemistry, because they are used to just memorizing concepts without understanding how to apply them in problem solving (José et al., 2021). By using effective learning techniques, teachers can help students understand the concept of the basic laws of chemistry better.

Students studying chemistry have different levels of knowledge and experience, which can be a challenge for teachers in meeting each student's needs effectively (Bamiro, 2015). It is important to address these differences by using tailored strategies and teaching models so that all students can succeed. One innovative learning model that can hone critical thinking ability is Project-Based Learning (PjBL). The PjBL model is suitable for learning chemistry because it allows students to develop creativity, critical thinking, as well as collaboration and communication skills. Research shows that the use of PjBL can improve student learning outcomes, including critical thinking skills and creativity (Arafah & Hakim, 2022). PjBL also helps students understand chemistry concepts better and build a positive attitude towards the material (Nagarajan, 2019).

In the context of chemistry learning, PjBL can be used to develop important 21st century competencies, such as collaboration and communication skills (Zhao, & Wang, 2022). PjBL enables students to learn through direct engagement with relevant and meaningful projects, thereby enhancing students' critical thinking ability, creativity, and engagement. Research has shown that PjBL in chemistry education can improve student learning outcomes, including critical thinking skills and creativity. Apart from that, PjBL also helps students understand chemistry concepts better and build a positive attitude towards the subject.

The Project Based Learning (PjBL) model has many advantages in the field of education. PjBL has been proven to be able to develop students' soft skills, such as self-efficacy, work abilities and practical competencies (Ademola et al., 2023; Bowen, 2022). In addition, PjBL improves learning outcomes, engagement, positive attitudes towards learning, and students' skills to apply knowledge in real situations (Blatti et al., 2019; Almulla, 2020). This model is also effective in improving students' numerical literacy, digital literacy and communication skills, as well as increasing their interest and learning skills.

Overall, PjBL provides a student-centered, contextual and inquiry-based learning approach, which contributes to the holistic development of students. Although many studies support the effectiveness of PjBL in improving critical thinking skills and learning outcomes, there is still a gap in understanding regarding the effective implementation of PjBL in various chemistry education contexts. This research aims to explore the most effective specific strategies for implementing PjBL in improving critical thinking ability in chemistry education.

Method

The method used in this research is analytical descriptive research based on categorizing critical thinking skills. This categorization refers to the N-Gain Score value. The subjects in this research were class X E1 SMAN 1 Gowa, totaling 35 students. Aspects of critical thinking skills, according to Ennis (2011), are categorized include:

Table 1. Aspects of Critical Thinking Ability

Aspects of Critical Thinking Ability	Description
Interpretation	Understand and explain the meaning of the information provided. Identify primary and supporting arguments and recognize the implications of the information provided.
Analysis	Break information into smaller parts and understanding the relationships between these parts. Identify patterns and

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	cause-effect relationships and understand how the parts contribute to the whole.
Inference	Description of reasonable conclusions based on the information provided. Relates the info provided to previous knowledge or experience and makes rational assumptions.
Deduction	Make logical decisions and conclusions based on the premises or information provided. Relates to the use of logical rules in inferring information.
Evaluation	Assessing the value or quality of information, arguments, or actions. Identify the strengths and weaknesses of arguments, recognize bias, and make relevant decisions based on ethical considerations.

The instrument used is a structured essay test with seven items on the concept of chemical equilibrium. This instrument reveals critical thinking skills in interpreting, analyzing, deducing, inferring, and evaluating. The content validity of the questions is proven by presenting them to a chemist. In line with Gregory's (2007) statement, he stated that checking content validity can be carried out by asking experts in the field to assess the items created. To determine the increase in measured critical thinking skills, the data obtained was then analyzed using the average gain score (N-gain) developed by Hake (1999) through the following equation.

$$g = \frac{S_{post} - S_{pre}}{S_{m\ ideal} - S_{pre}}$$

The average N-gain values obtained are interpreted based on Table 1 below:

Table 2. N-Gain Score Category

N-Gain Score	Category
N-Gain > 70%	High
30% < N-Gain < 70%	Middle
N-Gain < 30%	Low

Results

The learning implementation begins with giving a pretest to determine the student's initial abilities. Next, learning is carried out by implementing the Problem-Based Learning model on the concept of basic laws of chemistry. The pretest and posttest results for each indicator of critical thinking skills are presented in Figure 2.

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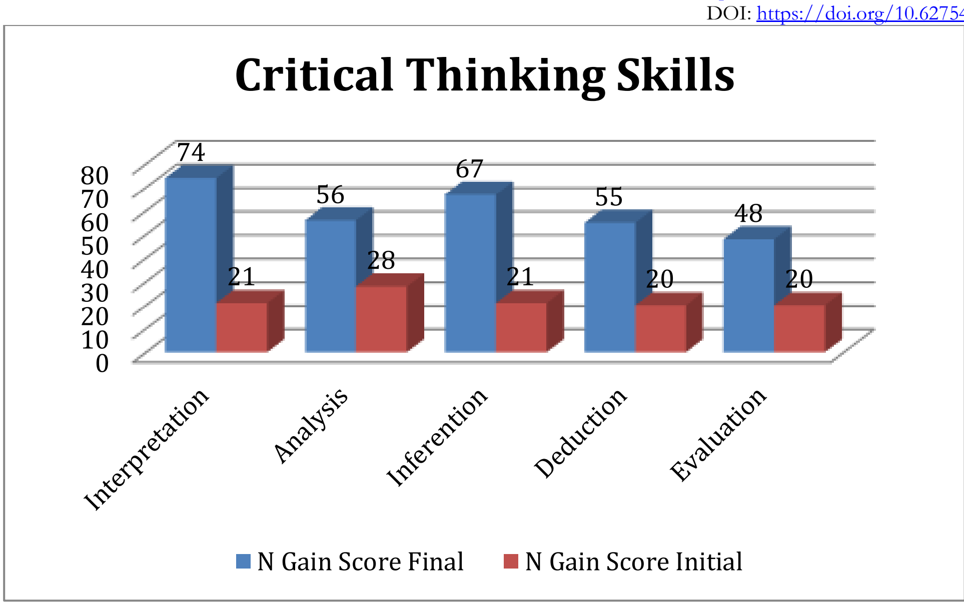

Figure 1. N-Gain Score Analysis for Each Critical Thinking Ability Indicator

Improvement in critical thinking skills for each indicator can be seen from the scores obtained for each question. The following is the percentage increase in indicators of critical thinking ability, which can be seen in Table 3.

Table 3. N-Gain Score

Critical Thinking Ability Indicator	N-gain (%)	Category
Interpretation	67	Middle
Analysis	39	Middle
Inferention	59	Middle
Deduction	45	Middle
Evaluation	36	Middle
Average	49,2	Middle

In developing students' critical thinking skills, it is essential to understand and analyze their skills to interpret information and break it down analytically. The following test results documentation aims to provide a comprehensive picture of students' interpretation and analysis skills, an essential foundation for learning and developing their critical thinking skills.

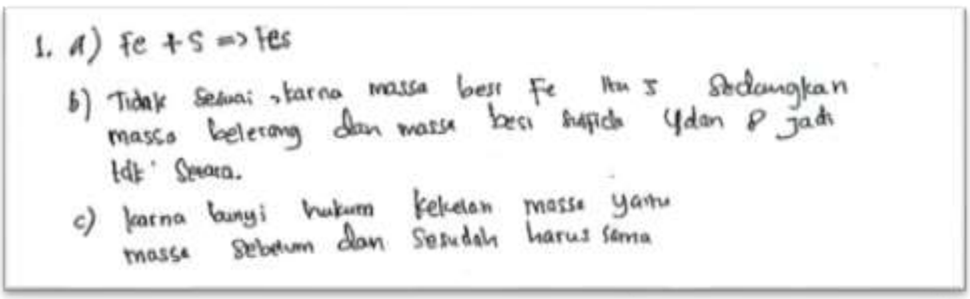

Figure 2. Documentation of Students' Critical Thinking Ability Test Results for Interpretation And Analysis Indicators

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Focusing on deduction and evaluation indicators is essential to understand students' critical thinking skills. The following test results documentation is structured to provide a detailed picture of how well students can make logical deductions from given premises as well as their skills to evaluate arguments and information. Through an emphasis on indicators of deduction and evaluation, this document will provide valuable insight into students' skills to infer relevant information and assess the quality of arguments, which are essential aspects in the development of their critical thinking skills.

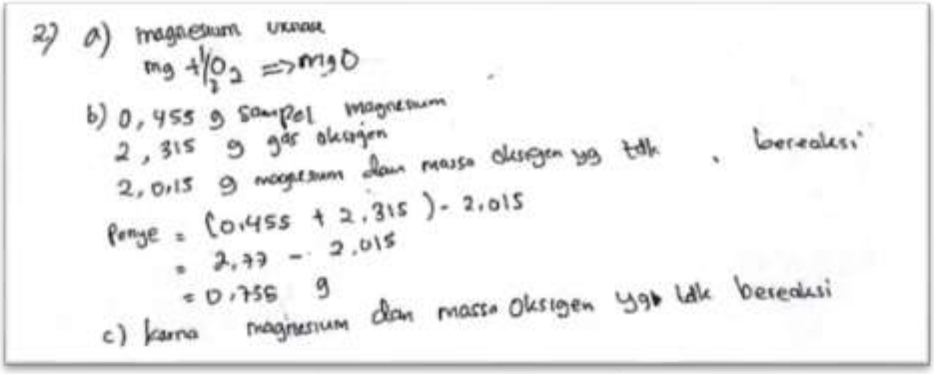
2) a) magnesium
mg + 1/2 O2 => mgO
b) 0,455 g sampel magnesium
2,315 g gas oksigen
2,015 g magnesium dan massa oksigen yg tdk bereaksi
Penye = (0,455 + 2,315) - 2,015
= 2,77 - 2,015
= 0,755 g
c) karna magnesium dan massa oksigen yg tdk beredusi

Figure 3. Documentation of Students' Critical Thinking Ability Test Results for

Deduction And Evaluation Indicators

Evaluating students' critical thinking skills and focusing on inference indicators is very important. This test results documentation aims to provide an in-depth understanding of how well students can make reasonable and relevant conclusions based on the information provided. By highlighting indicators of inference, this document will provide valuable insight into students' abilities to connect information, read between the lines, and use prior knowledge and experience to reach appropriate conclusions. This provides an essential foundation for the development of practical critical thinking skills.

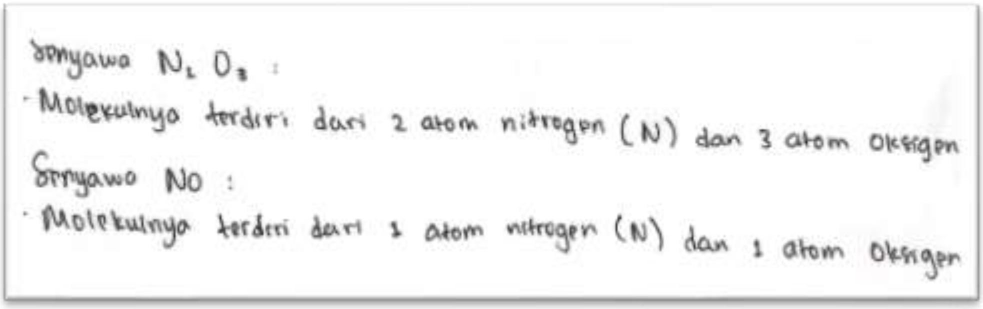
Senyawa N2 O3 :
- Molekulnya terdiri dari 2 atom nitrogen (N) dan 3 atom oksigen
Senyawa NO :
- Molekulnya terdiri dari 1 atom nitrogen (N) dan 1 atom oksigen

Figure 4. Documentation Of Students' Critical Thinking Ability Test Results

Inference Indicators

Discussion

From some of the data displayed, especially in Figure 1, it can be seen that there is a significant increase in critical thinking skills after implementing the PjBL model. The PjBL model allows students to take an active role in learning, enabling them to develop critical thinking skills (Zhao et al., 2023). The learning stages in PjBL combine activities that can hone critical thinking skills such as analysis, research, inference, strategy, and tactics (Wang, & Abdullah, 2024).

The PjBL model, from several studies, has been proven to develop critical thinking, collaboration, creativity,

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and communication skills, which are needed in the modern world of work (Anazifa & Djukri, 2017). Likewise, Situmorang et al (2022), concluded that PjBL innovation effectively improves critical thinking skills and increases student competence in chemical analysis skills.

In addition, He et al. (2024) support the notion that project-based learning can develop students' critical thinking abilities. This research emphasizes the importance of PjBL in improving critical thinking and histological concepts. In addition, Markula & Aksela (2022) discuss how the PjBL model can improve critical thinking, creative thinking, collaboration, and communication skills in physics education.

Solving problems in meaningful projects helps students better understand the theory and application of a concept. The PjBL model encourages the relevance of lesson concepts to the real world so that the learning experience is much more meaningful (Lahlafi et al., 2012).

Based on Figure 2, shows that students still need to be more capable in the process of evaluating information and answers. Many students may need to be more accustomed to critically evaluating the information they receive. Popular culture, social media, and online information often flood us with information without providing a framework for evaluating its truth or reliability (Walraven et al., 2013). Research has shown that students focus more on evaluating sources than understanding more about the content of those sources. Other research also shows that some students need more discernment in identifying quality sources of information and have difficulty validating sources effectively (Lahlafi et al., 2012).

The critical thinking skills graph also displays students' analytical and deduction abilities that need improvement. Analysis and deduction skills require structured and ongoing practice. Many educational programs do not focus sufficiently on developing these skills, and students may lack adequate practice to hone their analytical and deductive skills (Putri et al., 2023). In addition to this, deficiencies in logical reasoning can also impact students' skills to engage in deductive reasoning effectively, which is critical for analytical thinking (Murphy et al., 2014).

Mutakinati et al. (2018) show that through project-based learning, students can show their creativity in working on a project and improve their interpretation skills. Robherta et al. (2021) highlight that project-based learning encourages students to carry out independent interpretations to achieve meaningful learning outcomes. Additionally, Sumarni & Kadarwati (2020) found that project-based learning can increase students' motivation and critical thinking more effectively than traditional learning methods, further emphasizing its positive impact on interpretation skills.

Anazifa and Djukri (2017) researched the effectiveness of project-based learning in improving students' thinking abilities, which essentially involve inference and deduction. Emphasize that project-based learning can develop thinking skills to provide real solutions, teamwork, investigation, data collection skills, presentation skills, and evaluation of learning processes and outcomes, all of which require strong inference and evaluation abilities. Antonio & Prudente (2023) specifically investigated the influence of project-based learning on scientific thinking skills, which involve deduction and evaluation processes. Sasson et al. (2018) investigated students' critical thinking and writing skills in project-based learning, highlighting the importance of evaluation and deduction in academic assignments.

From the data and documentation in Figure 2 for critical thinking skills, indicators related to interpretation obtained an N-gain score of 67%. This indicates that students have quite high competence in interpreting information or data. In other words, students can understand and interpret information received or obtained from various sources. In addition, students can draw conclusions and make decisions based on this information. The PjBL model allows students to build knowledge by engaging in problem-solving activities in the real world, where the process involves the skills to design investigations, analyze information, and report findings, which are essential skills in interpreting or interpreting information effectively (Doyan et al., 2024; Ndiung & Menggo, 2024).

Apart from interpretation skills, project-based learning has also been proven to significantly improve

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students' critical thinking skills, especially students' analytical thinking skills. In the PjBL model students are more encouraged to engage in analytical thinking processes (Suradika et al., 2023; Situmorang et al., 2022). The analysis capability obtained an N-gain score of 39%. This indicates that students are quite capable of identifying patterns and relationships in information. However, students still need to improve their skills to break down complex problems into smaller parts systematically and to identify the most relevant information. From the two indicators of critical thinking skills, through the implementation of PjBL, students have quite good abilities in interpreting information but still need hard work to analyze information better.

Several studies have proven that project-based learning is effective in improving students' information deduction abilities by fostering critical thinking, problem-solving skills, argumentation, and interpretation skills in various educational contexts (Zhang, & Ma, 2023). The skills to deduct information is also an indicator of critical thinking ability. The data shows that the N-gain score for deduction skills is 45%, which has increased. The data proves that students experience more deductive reasoning, although the increase is not too large. This shows that students still need to improve in deductive reasoning. It can be indicated that students have difficulty in applying logical rules and principles to arrive at valid conclusions from given premises. Students still need practice to identify logical argument structures and draw valid conclusions.

Based on Table 3, the lowest critical thinking indicator is evaluation skills. However, from the results of the N-Gain data analysis it is still in the medium category, which allows for improvement in critical thinking skills. The PjBL model is able to increase students' skills to evaluate their own work critically and also the work of their friends, which ultimately fosters a culture of reflective practice (Zhang & Hwang, 2022). From the data, the lowest indicator of critical thinking skills is evaluation skills, with an N-gain score of 36%. This indicates that students still need to be able to evaluate information, arguments, or claims critically. There are several factors that can cause low student evaluation abilities. Among them is a limited understanding of a concept or material. Other factors can originate from the teacher's limitations in managing the learning process in the classroom. Based on the results obtained, students' critical thinking skills can be improved through the implementation of the Project-Based Learning model.

The next critical thinking indicator, inference, obtained an N-gain score of 59%. This shows that students have moderate or quite good abilities in concluding information. Students can make connections between information and draw conclusions based on that information. However, students need to practice their skills to determine the most essential things in information. From this, the inference skills can be increased through the PjBL model.

The differences in results between these studies may strengthen the argument that the success of PjBL is highly dependent on appropriate implementation and the teaching context used. A more focused implementation of evaluation and assessment could help address the weaknesses discovered in my research, and ensure more equitable improvement across all indicators of critical thinking skills.

Conclusion

Based on the results of the research that has been conducted, students' critical thinking skills have increased, as shown by the difference in pretest and posttest scores for each critical thinking indicator. This is proven by the average value of the N-Gain Score for each critical thinking skills indicator, which is in the medium category. From this research, further research can be recommended. First, further research could focus on specific strategies to improve students' evaluation skills, considering that this indicator had the lowest score in the current study. Implementing teaching techniques that focus more on evaluation and providing in-depth feedback could be an area of exploration. Second, variations in PjBL teaching methods across different chemistry education contexts also deserve further research to understand how different learning environments may influence the effectiveness of PjBL. Further research should also include longitudinal analyzes to evaluate the long-term impact of PjBL on critical thinking skills and other relevant skills. Finally, an exploration of the use of digital technology in PjBL can provide additional insight into how technology integration can support and enhance project-based learning processes. By exploring these

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recommendations, future research can make a more comprehensive contribution to the understanding and development of PjBL in chemistry education.

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