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STEM-PjBL Learning Model To Enhance Critical Thinking Skills of Students on Magnets, Electricity, and Technology

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Abstract: This study aims to enhance the critical thinking skills of fifth grade elementary school students on topics of magnet, electricity, and technology through the STEM-PjBL model. The study involved 20 students. The research design employed was classroom action research conducted in three cycles. Qualitative data analysis techniques were utilized. The analysis of students' critical thinking skills focused on five indicators: Identify Question at Issue, conceptual understanding, ideas connection, assumptions, and inferences, with five levels of achievement. The results showed an improvement in critical thinking skills, with 75% of students' responses at a very good level of critical thinking, 35% at the mastering level in cycles I and II, and 45% in cycle III, along with 35% at the competent level. Meanwhile, those at the developing level were 15% in cycles I and II, increasing to 20% in cycle III. The remainder was 5% at the emerging stage in cycle I and 10% in cycle II. There were 5% at the absent level in cycle I. Therefore, the STEM-PjBL model can be considered an effective approach for students to enhance their critical thinking skills in IPAS learning and to support their active engagement in the classroom.

Keywords: Critical Thinking; Elementary School; Science Learning; STEM-PjBL

Introduction

The educational landscape in the 21st century is increasingly dynamic and demands innovation in education. Jannah et al. (2020) explain that 21st-century learning is based on technological demands balanced with the needs of the industrial revolution 4.0, aiming to equip students with life skills. To be competitive in the 21st century requires new competencies known as 21st-century skills, which consist of creative thinking skills, critical thinking and problem-solving skills, collaboration, communication, and creativity and innovation, collectively known as the 4Cs (Zubaibah, 2019). In the realm of education, the development of 21st-century skills has been pursued. Several efforts have been implemented through the transformation from the 2013 curriculum to the Merdeka curriculum. The Merdeka curriculum represents an effort to enhance the quality of learning in schools, focusing on essential subjects and the development of students' character profiles based on Pancasila. One characteristic of this curriculum is the implementation of project-based learning (PjBL) (Handayani et al., 2023). Anwar, (2022) states that the Merdeka curriculum is an intracurricular learning curriculum that implements the PjBL model. This model emphasizes exploration, research, interpretation, synthesis, and information to produce meaningful learning experiences for students.

IPAS learning is a subject that combines Natural Sciences (IPA) and Social Studies (IPS) (Nuryani et al., 2023). Sciences and Social Studies (IPAS) investigate the interactions between inanimate objects and living beings in the universe and how they interact with each other. IPAS also explores human life both as individuals and as social beings interacting with their environment (Afifah et al., 2023). In Sciences and Social Studies (IPAS) learning activities, emphasis is placed on the skills of collaboration, critical thinking, and communication (Nihayatul Fadlilah & Purbasari, 2024). Sciences and Social Studies (IPAS) plays a role in realizing the profile of

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Pancasila students as an ideal representation of Indonesian learners (Dinda Sartika et al., 2021). Sciences and Social Studies (IPAS) is expected to develop students' scientific attitudes, including high curiosity, analytical thinking, critical thinking, objective, systematic approaches, open, honest, and responsible (Fanani et al., 2022). The goal of Sciences and Social Studies learning is to provide students with the opportunity to study inquiry-based knowledge, acquire the ability to master themselves and their environment, and gain an understanding of the concepts being taught (Yulia Friska & Retnawati, 2023).

Research data indicates that the process of teaching Natural Sciences in elementary schools often employs the lecture method, which results in students struggling to understand the material and having low critical thinking skills (Yasifa et al., 2023). Based on the research by Hayati dan Setiawan, (2022), it was found that 1) the critical thinking ability of fifth-grade students in Natural Science learning at SDN 3 Brabowan, Blora Regency, is influenced by two factors: internal factors and external factors. Internal factors include student characteristics, reading ability, learning motivation, writing ability, and student habits. External factors include the implementation of teaching by the teacher and the routines established by the teacher for the students. Additionally, 2) the critical thinking ability of fifth-grade students in Natural Science learning at SDN 3 Brabowan, Blora Regency, is relatively weak, and 3) the low critical thinking ability of these students in Natural Science learning is attributed to their poor language skills and low reasoning ability.

Based on interviews with fifth-grade teachers conducted in January 2024, a common issue faced by teachers in the learning process is the low critical thinking ability of students. This is supported by observations made by researchers, indicating that during the learning process, students tend to be inactive in asking questions, engaging in discussions, and performing problem-solving analyses related to the learning activities. As a result, the teaching and learning process, which should be student-centered, is dominated by the teacher acting as the primary source of knowledge.

The researcher also conducted a critical thinking skills test on the Natural Sciences and Social Studies (IPAS) subjects of magnets, electricity, and technology. The results showed that 14 out of 20 students (70%) did not meet the established Learning Objectives Achievement Criteria (KKTP) of 75%. This was evident from the symptoms observed during the learning process, where students tended to merely read materials from books, memorize texts, and struggled to understand the material. In response to this issue, it is recommended that teachers implement learning strategies that encourage active participation, enhance critical thinking skills, and help students achieve the established learning objectives.

One solution implemented to enhance critical thinking skills is the use of the STEM-Project Based Learning (PjBL) model (Chung et al., 2022). This learning model provides projects and student-centered learning activities in the form of group work. The subjects of magnets, electricity, and technology, when taught using STEM project-based learning, involve students in critical thinking. The application of STEM project-based learning promotes students' knowledge and understanding through these projects. Students gain experience and apply their knowledge in real-life contexts through the creation of STEM projects.

This study aims to enhance students' critical thinking skills in Natural Sciences and Social Studies (IPAS) learning on the topics of magnets, electricity, and technology through the implementation of STEM project-based learning.

Method

This study employs Classroom Action Research (CAR) utilizing the Kemmis and McTaggart research model (Kemmis & Robbin McTaggart, 1990). Classroom Action Research involves teachers conducting research within their own classrooms through self-reflection, aimed at improving their performance as educators to enhance student learning outcomes (Pandiangan, 2019). In Classroom Action Research, one cycle consists of four stages: planning, implementation/action, observation, and reflection (Ardiawan & Wiradnyana, 2020). Subsequent cycles are based on reflections from previous cycles.

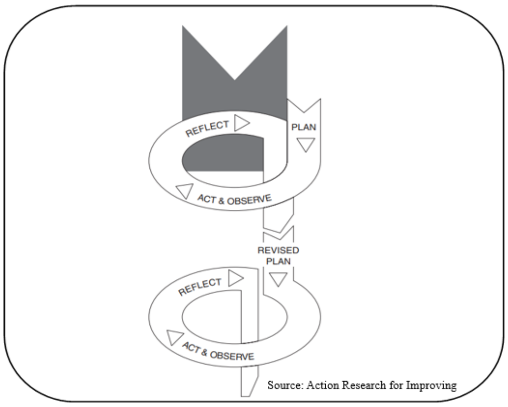

Figure 1. Models and Stages of PTK

Participants

This study was conducted during the academic year 2024-2025 in a fifth-grade class at a public elementary school in South Tapanuli District, Indonesia. The research involved 20 students, comprising 8 males and 12 females. The research was conducted from April to June 2024.

Research procedure

Classroom action research is designed through several cycles, and is adjusted to the conditions and results of reflection on the achievement of the expected improvements in the previous cycle, in accordance with the actions taken. Each cycle consists of four components, namely planning, action, observation, and reflection. With the following chart:

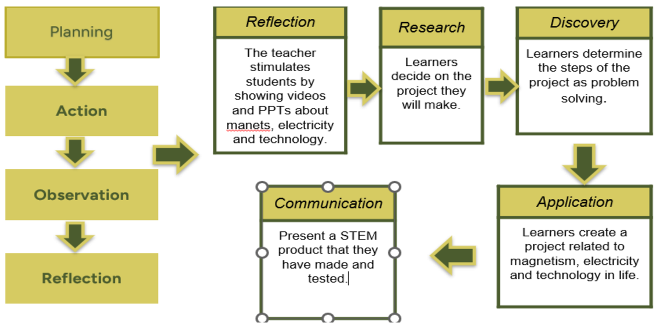

Figure 2. STEM-PjBL learning steps

Data Collection Techniques

Data collection in this Classroom Action Research included semi-structured interviews, classroom observations, students' reflective journals, research notes, and critical thinking skills tests.

Semi-structured interviews

Interviews conducted by researchers to obtain and understand in-depth information on student conditions related to the development of students' critical thinking skills while following the STEM-PjBL learning model. Interviews were conducted during the learning process and after the learning process to eight randomly selected students. Below are examples of semi-structured interview questions:

- Did implementing STEM-PjBL improve your critical thinking skills?
- Did the project you created have any influence on your learning? Explain!

Classroom observation

Observations were made by observing and recording every aspect of students' critical thinking skills that emerged during learning with the STEM-PjBL model. In the observation process, the researcher was assisted by two *observers* (teachers) who combined on the observation sheet. The observation sheet used is related to the indicators of critical thinking skills. At the beginning of the lesson, the researcher asked questions that were expected to trigger students' curiosity about the subject matter.

- What do we use to illuminate our activities at night?
- What if there is no electricity in our lives?

Reflective Journals

Journal reflections contain daily notes in the form of student responses during learning using the STEM-PjBL model. Journal reflections are filled in by students at the end of each meeting in learning with the STEM-PjBL model and the development of critical thinking skills during the learning process. Below are common questions that arise in reflective journals.

- How was your learning experience during the learning process using the STEM-PjBL learning model?

Student Worksheets

At the end of the meeting that has been planned and outlined in the Learning Implementation Plan (RPP), students are given worksheets containing several questions that must be answered by each student. The purpose of this worksheet is to determine the impact of the STEM-PjBL approach that integrates with the topics of magnetism, electricity and technology. The questions refer to the critical thinking skills assessment rubric related to magnetism, electricity and technology. Below is an example of the questions given:

- What would you do if your younger sibling overuses electricity?

Analysis and Validity

Data analysis in this study followed the qualitative analysis procedures of the Miles and Huberman model (Miles & Huberman, 1994). Data presentation utilized the Analysis Interactive model by Miles and Huberman, which involves four stages. The initial stage is data display, followed by data reduction where changes from innovative components are analyzed piece by piece. The third stage is data analysis, which includes deep understanding of events while considering other aspects in field notes, often accompanied by underlying reasons. The final stage is verification and conclusion validation.

Result and Discussion

This study aims to analyze students' critical thinking skills using the STEM-PjBL model (Dewi et al., 2023). The research was conducted at a public elementary school in South Tapanuli District, focusing on the topics of magnets, electricity, and technology. The study consisted of three cycles conducted over eight sessions during the academic year 2024/2025.

1. *Learning Implementation*

The learning activities followed the STEM-PjBL syntax (Laboy-Rush, 2010), which includes reflection, research, discovery, application, and communication.

The description of these learning steps is encapsulated in Table 2.

Tabel 1. Description of Learning Steps

Learning Steps	Cycle 1	Cycle 2	Cycle 3
			Deskripsi
Reflection	Students were presented with a video and PowerPoint presentation on magnets, electricity, and technology to explore their existing knowledge. Through these materials, students engaged in reflective thinking, prompting a desire to solve problems.		
Research	Students conducted the project, delving deeper into the subjects of magnets, electricity, and technology. They sought information from books and videos to develop their projects on magnets, electricity, and technology.		
Discovery	Students were tasked with designing and discussing their project plans, integrating each STEM component.		
Application	Students implemented their project according to the established plan and completed it within the scheduled timeframe.		
Communication	Students presented their project outcomes, and teachers evaluated them using project assessment rubrics.		

a. Reflection

The researcher prepared learning materials and media tools for students to use during the reflection stage of all three cycles. Using a projector, the researcher delivered content and distributed modules covering topics on magnets, electricity, and technology to stimulate both cognitive and affective activities among students during the learning process.

This method was designed to enhance students' understanding of the subject matter. Presenting materials through audio-visual media facilitates a deeper grasp of conceptual content. Throughout the reflection activities, the researcher also posed probing questions aimed at prompting students' everyday observations related to the material. These prompting questions contribute to fostering critical thinking skills during the reflection stage.

The researcher utilized a projector as a instructional tool to elucidate the taught material with the aim of engaging students. During the first cycle, it was found that none of the students were familiar with the term STEM-PjBL. The researcher proceeded to provide a detailed explanation of the STEM-PjBL model, outlining the stages of learning to be undertaken over three cycles. Projects related to magnets, electricity, and technology such as toy magnet cars, electric fans, series circuits, and parallel circuits were conceptualized and presented. The researcher informed the students that each group was required to successfully complete their STEM-PjBL project. Each project was to be completed within three cycles and presented to the class. Participants formed four groups, each comprising 5-6 individuals, to engage in discussions, gather information, and work on STEM-PjBL projects related to magnets, electricity, and technology.

b. Research

During the research phase across the three cycles, the researcher asked students to comprehend the material presented using PowerPoint and video. The researcher also guided students in seeking the necessary information through the IPAS textbook. Each group was instructed to write down and retain important information about magnets, electricity, and technology.

Each group actively studied the material from the PowerPoint presentations, videos, and the IPAS textbook, noting significant and useful findings. At this stage, the learning process was student-centered, as students engaged in understanding, seeking, analyzing, and verifying the information obtained. This is illustrated in the following interview excerpt:

Our group used various sources to learn more about magnets, electricity, technology, and the tools needed for our project. We discussed within the group to understand the STEM project we were working on.
(Interview, Student 13, May 1st, 2024)

The interview results indicated that students did not solely rely on textbooks as their learning source; they also utilized additional learning resources such as YouTube and the internet. This approach helped students enhance their critical thinking skills by building conceptual understanding through a variety of learning sources, enabling them to complete tasks more efficiently.

c. Discovery

The researcher reviewed the material on magnets, electricity, and technology to help students recall and prepare. Subsequently, the researcher assigned tasks necessary for producing STEM-PjBL projects related to magnets, electricity, and technology. The researcher reminded students that their projects must encompass the elements of science, technology, engineering, and mathematics (STEM).

Table 2. STEM projects components

Components	Cycle 1	Cycle 2	Cycle 3 Description
Science	Identification of magnetic force and electromagnetic induction.	Identification of parallel and series electrical circuits.	Identification of technology in everyday life.
Technology	Designing using YouTube as a guide.	Utilizing batteries, lamps, switches, dynamos, and cables as main materials; designing using YouTube as a guide.	Electrical projects and fans as examples of technology in daily life.
Engineering	Techniques for selecting and assembling materials used.	Techniques for selecting and assembling materials used.	Linking projects with technology.
Mathematics	Measuring the speed of magnet toy cars.	Measuring the electromotive force generated.	Calculating costs and materials for technology in daily life.

During the project planning process, students utilized various resources to complete their projects and facilitate access to information throughout the learning activities.

d. Application

At this stage, across the three cycles, students worked in groups to apply the ideas they had learned to create STEM-PjBL projects related to magnets, electricity, and technology. They integrated science, technology, engineering, and mathematics into their projects. Once each group had gathered all necessary materials and tools, they began their projects according to their designs.

Figure 3. The process of creating various STEM-PjBL projects related to magnets, electricity, and technology.

Students were faced with challenges and problems that encouraged them to think critically and use their knowledge to solve issues. This is evidenced in the following reflective journal entries:

"*Learning by creating projects at school makes lessons more interesting and easier to understand and apply in daily life.*" *(Reflective journal, student 14, May 8, 2024)*

"*The learning process in this second cycle was very enjoyable because it taught us how to make a fan using simple materials.*" *(Reflective journal, student 9, May 13, 2024)*

Based on students' reflective journals, the implementation of STEM project-based learning allows students to enhance their learning skills, apply lesson content to everyday life, practice working in groups to create projects, and take responsibility for completing their projects (Rochim et al., 2021).

e. Communication

Communication is the final step in the STEM-PjBL syntax in this study. At this stage, each student group is allotted a maximum of five minutes to present their completed project at the end of each cycle. These presentations include a description of the materials used, the design, the production procedures, and the benefits of the project.

In the learning process, presentations are a crucial step for enhancing students' communication and collaboration skills, as well as receiving constructive feedback. The process of sharing information encourages students to develop their knowledge through research and discussion in their efforts to solve problems and achieve their goals (Tseng et al., 2013).

"*Group presentation activities made me confident and brave.*" *(Reflective journal, student 14, May 15, 2024)*

The above reflective journal entry demonstrates that the communication step is where students enhance their critical thinking skills by asking questions and evaluating the STEM products they created. At this stage, students improve their communication skills by presenting their solutions in front of the class. Collaborating in groups, providing feedback exchange sessions, and presenting final tasks have enabled students to practice their 21st-century skills (Chen & Yang, 2019).

Figure 4. Group Presentations

2. *Improvement of Critical Thinking Skills*

One of the data points used in this analysis is the results of students' critical thinking tests on the topics of magnets, electricity, and technology, conducted in each cycle. The results are shown in table 3 below.

Table 3. Analysis of students' critical thinking skills responses

Performance		Percentage %	
Levels	Cycle I	Cycle II	Cycle III
Mastering	40	40	45
Competent	35	35	35
Developing	15	15	20
Emerging	5	10	0
Absent	5	0	0

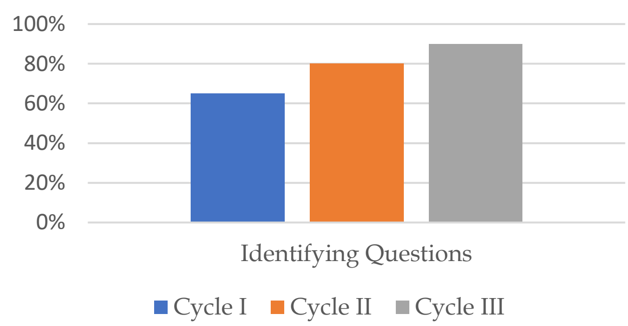

Figure 5. Critical Thinking Skills Test Results Graph

The observation of students' responses to the IPAS test on magnetism, electricity, and technology revealed a high level of critical thinking. A significant portion of students achieved mastery and competency levels. Referring to Table 3, it was noted that 75% of students' answers were at a very good level of critical thinking. Specifically, in cycles I and II, 35% of the responses were at the mastery level, and in cycle III, 45% were at the mastery level and 35% at the competent level. Meanwhile, 15% of students were at the developing level in cycles I and II, and this increased to 20% in cycle III. Additionally, 5% of students were at the emerging level in cycle I, which increased to 10% in cycle II. At the non-existent level, 5% of students were observed in cycle I.

The indicators of this analysis are based on SCIT 1020 (Rahmawati, Hadinugrahaningsih, et al., 2021), which can be observed through five components (Yakman & Lee, 2012). The five critical thinking components are:

a. *Identify Question at Issue*

Table 4. Identifying Questions Analysis

Aspects of Critical Thinking Skills	Cycle I	Cycle II	Cycle III
Identifying Questions	65%	80%	90%

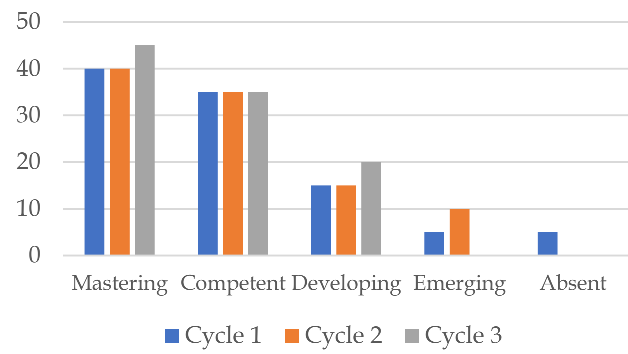

Figure 6. Identifying Questions Analysis Graph

Identifying problems is a high-level skill where students pinpoint issues and organize data based on relevant information (Trilling & Fadel, 2009). The analysis results showed an increase in the aspect of identifying questions in each cycle: cycle I recorded 65%, cycle II

80%, and cycle III 90%. The component of identifying questions emerged during the STEM project-based learning process on magnetism, electricity, and technology. This is evidenced by the observers' field notes and interview transcripts below:

The lesson was delivered by presenting PowerPoint and video materials on magnetism, electricity, and technology, followed by critical thinking questions that required specific skills and knowledge, such as, "If you lived in ancient times without electricity, how you would live without it?" Additionally, some questions posed to the teacher were, "Why could people in ancient times survive without electricity? How did they carry out activities without electricity?"
(Field notes, observer 1, May 6, 2024)

According to you, what is the relationship between studying magnetism, electricity, and technology in everyday life? What challenges do you feel in learning about magnetism, electricity, and technology?
(Interview, student 19, May 13, 2024)

Field notes and interview transcripts revealed that the implementation of STEM-PjBL engages students in Integrated Science, Technology, Engineering, and Mathematics (STEM) learning. Students practice identifying and analyzing each case during the course of activities. Moreover, they also cultivate their curiosity by posing questions and providing critical responses and answers to emerging issues (Yakman & Lee, 2012). STEM projects help students solve real-life problems through critical thinking and expand their knowledge and experience while investigating issues in real-world contexts (Hong et al., 2019).

b. *Conceptual Understanding*

Table 5. Conceptual Understanding Analysis

Aspects of Critical Thinking Skills	Cycle I	Cycle II	Cycle III
Conceptual Understanding	70%	75%	85%

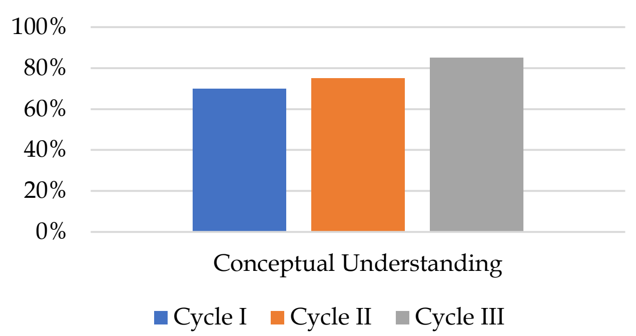

Figure 7. Conceptual Understanding Analysis Graph

Based on the table above, the analysis results of conceptual understanding in Cycle I were 70%, Cycle II were 75%, and Cycle III were 85%, indicating an improvement in conceptual understanding with each cycle.

Students must possess a strong conceptual understanding so that their ability to argue is based on what they know (Taliak et al., 2024). In this research, students were able to develop their conceptual understanding through STEM project activities, demonstrating how they could apply their initial understanding of concepts to solve problems (Elder & Paul, 1997).

I understand why magnets, electricity, and technology are useful for everyday life, because with technology, it helps humans to solve everyday life, for example, lights make it easier for humans to see objects at night.
(Reflective journal, student 5, May 15, 2024)

The reflective journal entry above indicates that students have a conceptual understanding of magnets, electricity, and technology. This suggests that project-based transdisciplinary learning enhances students' understanding and enables them to solve complex problems in real life (Susanti et al., 2021). This aligns with literature stating that STEM-PjBL helps students master content knowledge and develop skills through tackling complex problem-solving tasks (Rahmawati, Hadinugrahaningsih, et al., 2021) (Rahmawati, Adriyawati, et al., 2021).

c. *Ideas Connection*

Table 6. Ideas Connection Analysis

Aspects of Critical Thinking Skills	Cycle I	Cycle II	Cycle III
Ideas Connection	50%	70%	85%

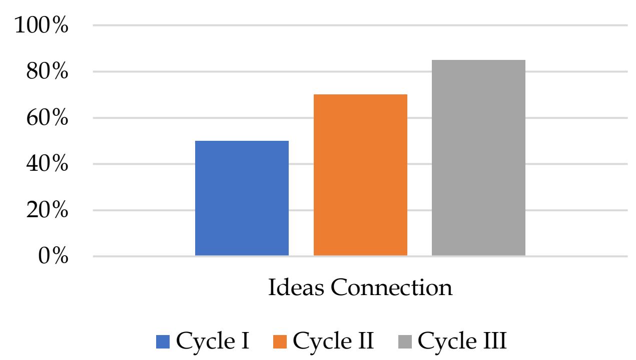

Figure 8. Ideas Connection Analysis Graph

In this learning process, students are trained to connect various ideas through group project activities. The analysis of idea connection in the table above shows results of 50% in Cycle I, 70% in Cycle II, and 85% in Cycle III. This indicates that students have been able to determine and use appropriate tools and materials in project creation, as evidenced by the following interview excerpt:

When making the fan, I knew which tool was suitable for making the fan blades spin. The tool is round and 8 mm in length, with a voltage of 1-6 V DC. I adjusted the tool end so that the fan blades could fit.
(Student interview, May 8, 2024)

The research findings above indicate that students can easily connect their knowledge of everyday tools suitable for project creation. Students can determine the types of materials, sizes, and the importance of decoration as tools for creativity to ensure the success of their projects (Afriana et al., 2016). This demonstrates that the integration of STEM-PjBL as contextual-based learning enhances student engagement and yields meaningful learning experiences through learning from their own environment (Glancy & Moore, 2013).

d. Assumptions

Table 7. Assumptions Analysis

Aspects of Critical Thinking Skills	Cycle I	Cycle II	Cycle III
Assumptions	55%	65%	80%

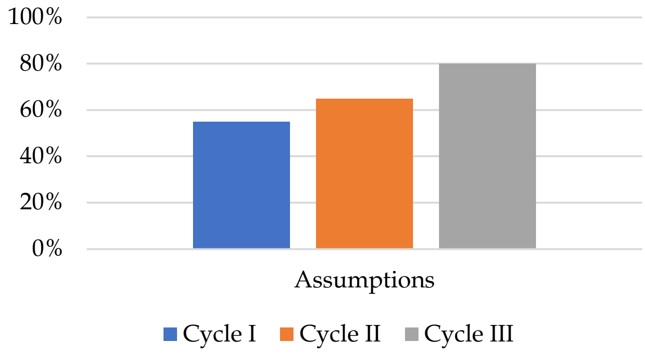

Figure 9. Assumptions Analysis Graph

The assumption is a logical estimation that can be substantiated by facts or information (Huber & Morreale, 2022). The results of assumption analysis in Table 7 obtained 55% in cycle I, 65% in cycle II, and 80% in cycle III, indicating an increase in assumption formulation in each cycle. Classroom observations revealed that student 14 in group 2 was able to articulate an assumption as follows:

"I can distinguish between parallel electrical circuits and series electrical circuits. Parallel circuits are arranged side by side, while series circuits are arranged in a sequential order."
(Classroom observation, student 14, May 8, 2024)

Student 14 demonstrated a good level of understanding, enabling them to express tested assumptions clearly and effectively. This illustrates that through project-based learning, students can comprehend the differences between parallel and series electrical circuits. STEM education encourages students to apply logical and scientific thinking that stimulates and enriches learning experiences. This behavior aligns with the definition of critical thinking involving making assumptions, examining different perspectives, and making decisions based on information (Brookfield SD, 2012).

e. Summary

Table 8. Summary Analysis

Aspects of Critical Thinking Skills	Cycle I	Cycle II	Cycle III
Inferences	80%	85%	90%

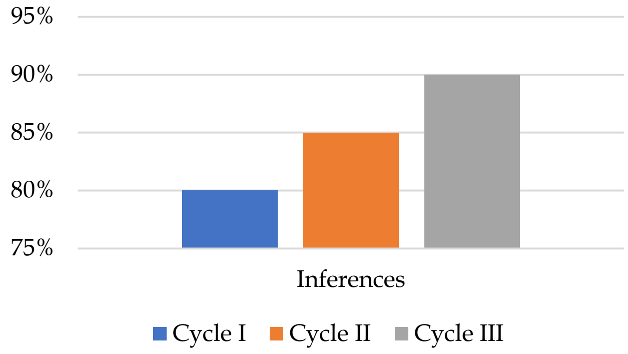

Figure 10. Inferences Analysis Graph

Inferences is one of the critical thinking skills that measures the ability to draw clear, valid, logical conclusions supported by adequate evidence (SCIT 1020, 2013). The results of the Inferences analysis in Table 8 obtained 80% in cycle I, 85% in cycle II, and 90% in cycle III, indicating improvement across each cycle. At the end of the magnet, electricity, and technology project, students were asked to reflect on their learning (Adriyawati et al., 2020). The following reflective journal entry demonstrates that 20 students attempted to articulate the outcomes of their group projects:

"Through this project, we gained a deeper understanding of how scientific principles can be applied in real life. For instance, the concept of aerodynamics that we learned theoretically in class became more tangible when applied in designing the fan blades."
(Reflective journal, student 9, May 13, 2024)

The above results indicate that integrating STEM-PjBL in IPAS learning can enhance students' critical thinking skills, as demonstrated by their ability to draw consistent, logical, and credible conclusions by examining evidence (Adriyawati et al., 2020).

Conclusion

Based on the results of research and discussion, it can be concluded that students' critical thinking skills on magnetic, electrical and technological materials have developed every cycle because the results of students' critical thinking tests are more dominant at the *mastering* level with an average of 42%. This can be seen from the five indicators of critical thinking, students' critical thinking skills in the indicator of identifying questions increased by an average of 12% each cycle and the concept understanding indicator increased by an average of 5% each cycle. While the indicators of connection of ideas and assumptions increased by an average of 15% each cycle and conclusions increased by an average of 5% each cycle. Overall, each indicator showed a significant increase in each cycle, indicating a positive and consistent increase in all indicators measured in the learning process using the STEM-PjBL model.

The STEM-PjBL model in class V of SDN No. 100605 Sitampa Simatoras can produce learning that improves students' critical thinking skills on the material of magnetism, electricity and technology. The implementation of this learning model involves students actively in every stage of learning activities, starting from the problem identification stage, research, planning, project implementation, to evaluating the results. Students are given the opportunity to apply the theory they learn in a real context through projects. Each stage of the project requires students to think critically, group discussions and project presentations also encourage students to develop communication and collaboration skills. Overall, it has shown positive results in improving students' critical, creative, and collaborative thinking skills in magnetism, electricity, and technology.

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Author Contributions
All authors contributed to drafting and finalizing this article. HDL was responsible for preparing the research instruments and data collection. YR contributed to the development of instruments and research design. HU played a role in the study's data analysis.

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Conflicts of Interest
The authors declare no conflicts of interest.

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