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Research Article

MAPPING STUDENTS' THINKING SYSTEMS IN CRITICAL THINKING BASED ON STEM PROJECT-BASED LEARNING EXPERIENCES

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Abstract
Critical thinking is an essential skill for students to develop. The objective of this research is to map students' thinking systems in critical thinking based on STEM project-based learning experiences. The method used is a mixed-method approach with an Embedded Experimental Model. The research subjects are undergraduate students in basic physics at the University of Jambi. Data collection is conducted through tests and interviews. The test instrument employs structured critical thinking questions based on the Halpern Critical Thinking Assessment (HCTA) indicators, while the interview instrument utilizes open-ended questions. Data analysis utilizes paired t-tests and coding to map students' thinking systems. The research results indicate an influence of STEM-PjBL learning on students' critical thinking abilities, supported by the analysis showing a moderate increase in students' critical thinking abilities. Additionally, based on mapping students' thinking systems, there is an increase in thinking system 2 by 56 answers. Moreover, thinking system 2 is nearly equivalent to thinking system 1 except in reasoning. In the fourth question and other aspects of critical thinking abilities, thinking system 2 is comparable to thinking system 1 and even more dominant in question number 3. This demonstrates an enhancement in students' critical thinking abilities after STEM project-based learning. This research provides new insights into the development of student's critical thinking skills, which can be beneficial for curriculum development and teaching practices in the STEM education field.

Keywords: Critical Thinking, Project, STEM, System

INTRODUCTION

Developing critical thinking skills is one of the main goals in science education today (Piergiovanni, 2014; Viennot & Décamp, 2018). Initially, efforts to develop critical thinking skills were separate from science taught in schools (Mulyani, 2019). The importance of critical thinking skills is why it has begun to be embedded in science taught in schools and colleges (Walsh et al., 2019). Critical thinking skills are also very important to be instilled in physics learning. Successful learning by involving critical thinking skills requires thinking processes such as predicting, analyzing, synthesizing, evaluating, reasoning, and so on (Tiruneh et al., 2016). Learning by embedding indicators of critical thinking skills in a material taught in class has proven successful in improving students' critical thinking skills in general (Mulyani, 2019; Suradika et al., 2023).

Critical thinking skills can help students in reasoning, reflection, and decision making (Putra et al., 2018; Tiruneh et al., 2017). Critical thinking skills can also help students in processing information and making logical decisions (Etkina & Planinšič, 2015). Critical thinking skills are associated with the top three levels of Bloom's taxonomy (Al-Salmani & Thacker, 2021). The top three levels of Bloom's taxonomy are analyzing, evaluating, and creating (Al-Salmani & Thacker, 2021).

Learning that can be a solution to improve students' critical thinking skills is by implementing the integration of sciences, technology, engineering and mathematics (STEM). The current learning development in physics education in recent years has changed from scientific-based learning to sciences, technology, engineering and mathematics (STEM) based learning (Arifin et al., 2021; Mulyani, 2019). This is inseparable from many countries that want to prepare their citizens to understand STEM and have multidimensional abilities to be used in modern life (Ngabekti et al., 2019). Future challenges require each individual to understand a variety of multidisciplines (Oktavia et al., 2023).

STEM is a combination of four fields of science integrated into problem-based learning (Mulyani, Betri, Marsidin, 2021; Park, 2016; Sanusi et al., 2022). The underlying characteristic of STEM is the so-called integrated learning design (Mutakinati et al., 2018), which is the integration of several disciplines consisting of science, technology, engineering and mathematics used to solve problems (Ngabekti et al., 2019; Nugroho et al., 2019; Pérez et al., 2017), as well as the importance of students' long-term academic success (Nugroho et al., 2019). STEM is an interrelated discipline that cannot be separated in learning (Afriana et al., 2016; Jang, 2016). The application of knowledge and skills is key in learning with the STEM approach, therefore providing a STEM approach can help in developing student resources.

In an educational perspective, the introduction of STEM can take the form of various activities, but in general, it usually includes changing traditional teaching strategies with a project-based approach (Noh & Khairani, 2020; Sumarni & Kadarwati, 2020). STEM in the implementation of learning is expected to provide meaning to students through systematic integration of knowledge, concepts and skills that are useful in developing students' problem-solving abilities (Afriana et al., 2016; Margot & Kettler, 2019; Tecson et al., 2021). The most important modern conception of STEM is the notion of integration, meaning that STEM is the intentional integration of different disciplines as used in solving problems (Noh & Khairani, 2020).

In this research, STEM will be the basis in determining the activities that students will do. Meanwhile, the learning steps are based on project-based learning (PjBL) steps. PjBL is a form of student-centered instruction based on three constructivist principles, namely learning is context-specific, learners are actively involved in the learning process and they achieve their goals through social interaction and sharing of knowledge and understanding (Anazifa & Djukri, 2017; Purwaningsih et al., 2020). PjBL as a form of teaching has clear links with other pedagogical approaches, such as problem-based learning (Siew & Ambo, 2018). The focus of both is for participants to achieve a common goal through collaboration. In their engagement with a project, students may encounter problems that need to be addressed to build and present a final product in response to a question. The main difference between the two is that while students in problem-based learning mainly focus on the learning process, PjBL needs to culminate in a final product (Chen & Yang, 2021).

Several studies have tried to implement Project-based learning (PjBL) in learning, such as in elementary schools, the implementation of PjBL to facilitate students' reasoning and comprehension skills reported positive results for the group that experienced Project-based learning (Nani & Kusumah, 2015). At the junior high school level, it was found that the experimental group using PjBL significantly outperformed the control group in the Environmental Knowledge Test and Science Attitude Survey (Al-Balushi & Al-Aamri, 2014). At the tertiary level, it was found that student lecturers who received PjBL learning can become better problem solvers (Yusnidar, Epinur & Nadilla, 2023), can benefit from formative assessment (Liu et al., 2016) and become more aware of learning objects which can then lead to improved learning (Barak & Assal, 2018).

The results of these studies make a good contribution to the learning process. This proposed research has similarities related to the Project Based Learning (PjBL) model applied in learning. The difference is that in this study, researchers integrate STEM as a learning approach and critical thinking skills as the outcome to be analyzed. To get an idea of the importance of this research, researchers conducted a review with the help of postviewer to obtain a novelty gap or urgency of this research. The review with Vosviewer was conducted on 501 articles published from 2018 - 2023. The themes that were reviewed with the postviewer process consisted of STEM, Project Based Learning and critical thinking skills as shown in Figure 1.

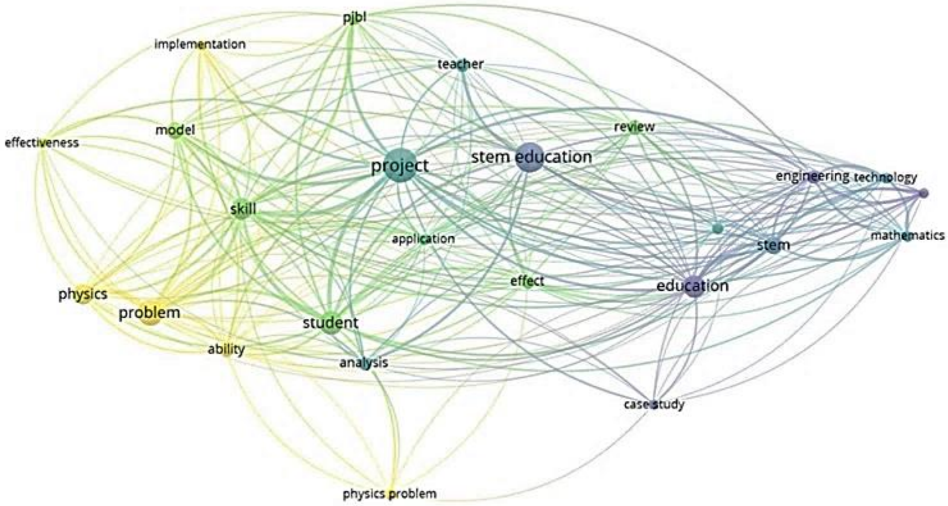

Figure 1. Vosviewer Review Results

Figure 1 depicts the overall pattern of relationships found in several previous studies related to the researched topic. When analyzed more specifically regarding PjBL and STEM research, Figure 1 indicates that this topic has been extensively studied. However, there has been no research focusing on linking PjBL and STEM with students' thinking abilities. Therefore, the objective of this research is to map students' thinking systems in critical thinking based on STEM project-based learning experiences.

RESULTS AND DISCUSSIONS

This research used a mixed method with an explanatory design. It aims to obtain in-depth information about students' critical thinking skills based on the application of STEM-PjBL. Quantitative research methods are used as the main data to assess students' critical thinking skills, while qualitative research methods are used to find out more about students' thinking systems and to confirm the answers to student descriptions that are not understood. The research subjects are undergraduate students in basic physics at the University of Jambi. Samples in quantitative and qualitative data collection were selected by purposive sampling technique. Students who became quantitative data collection samples were 70 students who were taking basic physics courses, while qualitative data collection samples were selected based on the findings of the results of quantitative data collection.

The Embedded Experimental Model design used in this study follows the procedure in Figure 2. The research began with giving a pretest to collect quantitative data. The pretest was conducted with the aim of obtaining the main data on students' critical thinking skills. The second stage is the implementation of STEM-PjBL. The material chosen in this study is rotational dynamics. After the implementation was carried out, in the third stage students were given a posttest. The posttest was conducted with the aim of seeing changes that occurred with students' critical thinking skills and changes in students' thinking systems. After the post-test data was analyzed, followed by an interview. The interview was conducted to find out more about the students' thinking system and to confirm the answers to students' descriptions that were not understood. In the final stage, test and interview data are interpreted together.

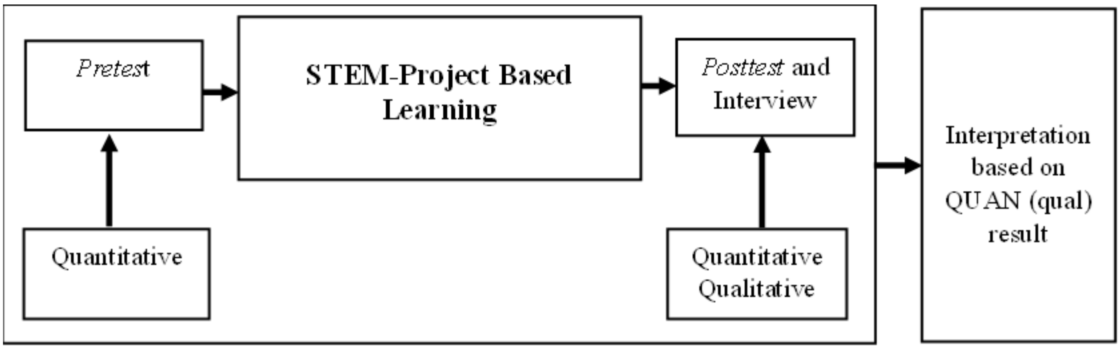

Figure 2. Embedded Experimental Model (Yuliati et al., 2018)

The data collection techniques in this study were tests and interviews. The test instrument is used as a tool that will provide information about students' critical thinking skills and mapping the level of thinking of students. The test instrument used was in the form of essay questions that were prepared based on the Halpern Critical Thinking Assessment (HCTA) indicators. The instrument grid is divided into several question indicators (Table 1). While the interview guideline contains questions asked to a group of students based on critical thinking questions given on the test. In the interview, each student was asked to explain again how they found the solution to the problem.

Table 1. Question indicators

Indicator
Analyzing the influence of torque on rotational motion of an object.
Analyzing Newton's second law in rotational motion.
Analyzing the moment of inertia of a rigid body
Formulating angular momentum in rotational motion.
Analyzing kinetic energy in rotational motion.

Data on students' critical thinking skills were obtained based on answer descriptions during the pretest and posttest. The distribution of critical thinking skills aspects is applied to each question and its assessment rubric. The scoring rubric is highly dependent on the condition of the questions used. All questions use identical scoring, with a maximum score of 4. This scoring system is adapted from the critical thinking skills assessment developed by Tiruneh et al (2017). The application of the scoring rubric is described in Table 2.

Table 2. Critical Thinking Ability Assessment Rubric

No.	Assessment Aspect	Score
1	Describes the problem correctly	1
2	Answered correctly	1
3	Mathematical decomposition is done correctly	1
4	The process of finding solutions is based on physics concepts	1
	Mean	4

Quantitative data analysis of students' critical thinking skills was carried out by determining statistical descriptions and normality prerequisite tests, pretest and posttest scores (paired t test or Wilcoxon test) and N-gain. Qualitative data analysis to explore more information related to mapping the level of thinking of students was carried out by following the interactive model procedure from Miles et al (2018). The qualitative analysis stage consists of data collection, data condensation, data display and conclusion drawing. Students' thinking ability was grouped into three thinking systems (Tiruneh et al., 2017), namely thinking system 1 for students who answered quickly and based on intuition, thinking system 2 for students who answered more slowly and with clear objectives based on aspects of critical thinking ability and thinking system 0 for students' blank answers.

RESULTS AND DISCUSSION

The assessment and mapping carried out in the research is part of seeing the effect of the application of STEM-PjBL on students' critical thinking skills. In addition, the results of the study will provide an overview of the mapping of students' thinking levels. The results of quantitative data analysis show that there is an effect of the application of STEM-PjBL in improving students' critical thinking skills. This result is evidenced by the paired t test of 12.48 with a significance of 0.00. The complete data is presented in Table 3.

Table 3. Data analysis results

Category	Scores
Paired t test	12.48
Signifikansi	0.00
N-gain Score	0.5
Effect size	2.1

The data in Table 3 shows that students' critical thinking skills improved after being taught with STEM-Project Based Learning. This can be seen from the N-gain value of 0.5. Although the N-gain value shows an increase in the moderate category, this still illustrates that STEM-Project Based Learning can be an alternative in developing students' critical thinking skills. Some previous studies stated that the increase in students' critical thinking skills after being given STEM-PjBL could be maximized due to several factors, such as practical experience (Siew & Ambo, 2018; Widarti et al., 2020). In STEM-PjBL, students are involved in projects that are real and relevant to the real world. This gives them the opportunity to experience direct application of the concepts learned, which can encourage critical thinking. Another factor is problem solving, where in the STEM context students are faced with challenges that require creative problem solving (Martin-Hansen, 2018). This forces them to think critically about various possible solutions, evaluate the effectiveness of those solutions, and make informed decisions. In addition, the collaboration and communication factors of project activities also influence the development of students' critical thinking skills (Surjanti et al., 2022). STEM-based projects often involve teamwork and active communication between students. Discussion, exchange of ideas, and collaboration can encourage students to question and debate ideas, resulting in critical thinking. All these factors can work together to create a learning environment that stimulates students' critical thinking. If this is not well conceptualized, it may be the cause of the moderate increase in students' critical thinking skills.

The results of deeper analysis related to students' critical thinking skills based on the results of qualitative data analysis. Mapping data on changes in students' thinking systems are shown in Figure 3.

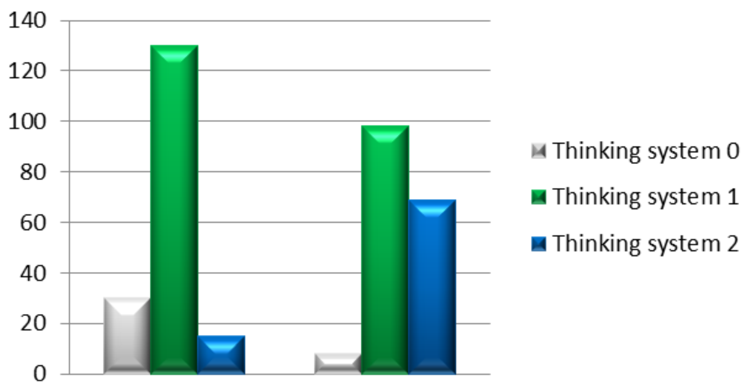

Figure 3. Students' thinking system in pre-test and post-test

Students' thinking ability was grouped into three thinking systems (Tiruneh et al., 2017), namely thinking system 1 for students who answered quickly and based on intuition, thinking system 2 for students who answered more slowly and with clear objectives based on aspects of critical thinking ability and thinking system 0 for students' blank answers. Five aspects of critical thinking skills are represented by each test question. The five aspects include Hypothesis Testing, Problem Solving and decision making, Likelihood and uncertainty analysis, Reasoning, Argument analysis (Ferty et al., 2019; Tiruneh et al., 2017).

Based on Figure 3, the thinking system shown by students in the pre-test for each question is dominant in thinking system 1. This result shows that before obtaining STEM-Project Based Learning (STEM-PjBL) learning, most students answer questions based on intuition in accordance with thinking system 1 (Tupas & Matsuura, 2019). According to some theories, there are several causes of students solving physics problems based on intuition, such as limited understanding of concepts (Anazifa & Djukri, 2017). If students do not have a strong understanding of the physics concepts underlying the given problems, they may tend to rely on their intuition to try to answer them. Another cause is time constraints (Maison et al., 2022). In exam or exercise situations that have time constraints, students may feel pressured to answer the questions quickly. This may cause them to rely on their intuition rather than considering more rational or knowledge-based solutions. In addition, uncertainty about the right strategy can be a factor that causes students to answer questions based on intuition (Mutakinati et al., 2018; Steinberg et al., 2009). In some cases, students may be uncertain about the right strategy to answer a particular physics problem. This may lead to the use of intuition as the easiest or most affordable solution.

During the post-test, the results in Figure 3 show that thinking system 1 was also more dominant but there was an increase in thinking system 2 by 56 answers in total. In addition, thinking system 2 is also almost comparable to thinking system 1 except in the reasoning aspect. These results indicate a change in the thinking system of students after obtaining STEM-Project Based Learning. STEM-PjBL changes the thinking system of students so that they are able to answer questions with clear objectives based on aspects of critical thinking skills. STEM theories argue that STEM learning often emphasizes the application of academic concepts in real contexts through challenging projects (Siew & Ambo, 2018; Zaniewski & Reinholz, 2016). This helps students understand the relevance of the subject matter to the real world and provides a clear goal in completing the projects (1). This has an effect on students' thinking system. In addition, STEM and PjBL learning often incorporate reflection and evaluation processes where students are asked to evaluate their own project outcomes and their learning process (Afriana et al., 2016). This helps them identify the goals they have achieved and evaluate their progress towards those goals.

Overall, this research illustrates that the integration of STEM with project-based learning can influence the development of students' critical thinking skills. There are many things to consider in developing students' critical thinking skills if you want to implement STEM-PjBL. These things include the projects designed must be relevant to real life and in accordance with the learning objectives set. It is important to actively involve students in the learning process, allowing them to lead their own exploration and take responsibility for their learning (2). Lecturers should support students in understanding the material, guide them in the problem-solving process, and provide constructive feedback to enhance their critical thinking. Finally, evaluation should be based on students' performance in projects and learning activities that require critical thinking, not just on their conceptual understanding**.**

The significant implications of this research lie within the context of STEM education (Science, Technology, Engineering, and Mathematics). One of the primary implications is a deeper understanding of how students develop their critical thinking skills through STEM project-based learning. This can aid educators in designing more effective teaching strategies to enhance students' critical thinking skills in the STEM fields. Additionally, with the mapping of students' thinking systems, educators can better identify areas where students may struggle or require additional assistance in developing critical thinking skills.

However, this research also comes with limitations that need to be considered. One of them is that mapping students' thinking systems may not always encompass all aspects of critical thinking skills. Some aspects of critical thinking skills may be challenging to measure or understand through the mapping methods used in this research. Moreover, the findings of this research may not always be generalizable to various learning contexts, as STEM project-based learning experiences can vary significantly depending on the environment and approach.

To enhance the effectiveness and relevance of this research, recommendations can be made for further studies. For instance, further research could broaden the scope of mapping students' thinking systems to include more variables that may influence the development of critical thinking skills. Additionally, research could integrate qualitative and quantitative approaches to gain a more comprehensive understanding of how students develop their critical thinking skills through STEM project-based learning. Thus, future research can provide deeper and more sustainable insights to improve STEM learning approaches focused on developing critical thinking skills.

CONCLUSION

The conclusion of this research is that there is an effect of STEM-Project Based Learning on students' critical thinking skills. This is supported by the results of the analysis of the improvement of students' critical thinking skills which are in the medium category. In addition, based on the thinking system at the time of the post-test there was an increase in thinking system 2 by 56 answers in total. In addition, thinking system 2 is also almost comparable to thinking system 1 except in the aspect of reasoning. This shows an increase in students' critical thinking skills after getting STEM-Project Based Learning.

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AUTHOR CONTRIBUTIONS

In the implementation of this research, tasks were divided among all members of the research team. The first author (Nehru) as the lead researcher was responsible for all research stages, particularly in the planning process and interpretation of research results. The second author (Sri Purwaningsih) as a research member was tasked with preparing teaching materials. The third (Cicyn Riantoni) and fifth authors (Devie Novallyan) as research members were responsible for preparing STEM project-based learning tools. Meanwhile, the fourth author (Doni Ropawandi) conducts the data analysis process and prepares assessment instruments.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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