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Promoting Students' Critical Thinking and Cognitive Learning Outcomes through Problem-Based Learning integrated with Mind-Mapping

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Abstract: Critical thinking and advanced cognitive abilities are vital competencies in 21st-century biology education, especially in complicated subjects like immunology. Innovative pedagogical methods are crucial for helping pupils overcome learning challenges and develop a deep understanding. This study examines the integration of problem-based learning (PBL) with mind-mapping approaches to enhance undergraduates' critical thinking and cognitive learning in immunology education, a field often regarded as complex and interdisciplinary. A quasi-experimental one-group pretest-posttest design was utilized, comprising 23 undergraduate students participating in a fundamental immunology course at the State University of Malang, Indonesia. Data were gathered using essay-based evaluations and evaluated employing paired t-tests, N-gain scores, and effect size computations. The results demonstrated substantial enhancements in both critical thinking and cognitive learning outcomes post-intervention, with impact sizes classified as big to very large. The extent of improvement differed among indicators, exhibiting moderate advancements in applying, evaluating, and analyzing, whereas synthesis showed only modest advancement. The results indicate that PBL combined with mind-mapping can effectively enhance higher-order thinking skills in complex subjects, providing dual scaffolding that aids students in organizing intricate concepts, visualizing relationships, and reinforcing higher-order thinking abilities.

Keywords: Cognitive Learning Outcomes; Critical Thinking; Mind-Mapping; PBL.

Introduction

In Education 5.0, lecturers and students incorporate technology into their teaching and learning processes. Technology is developing quickly; therefore, it's important to stay up to date. Education 5.0 is essential for a university's teaching and learning to remain relevant in the age of rapidly changing technology and to gain external recognition [1]. The significance of 21st-century competencies and critical thinking abilities required by Thai students for their technical and vocational education and training. Through the implementation of the 4 Cs, educators can impart 21st-century competencies, encompassing communication, critical thinking, cooperation, and creativity [2]. Contemporary humans navigate the complexities of the twenty-first century, necessitating enhanced competencies for Education, employment, and life achievement are interconnected [3].

Fascione characterized critical thinking as a deliberate, self-regulatory assessment that culminates in interpretation, analysis, evaluation, and inference, along with the elucidation of the evidence-based, conceptual, methodological, criteria-based, or contextual factors behind that assessment. The capacity for critical thinking (CT) is a vital skill which learners can acquire by learning and utilize in their current and future academic and professional environments [4]. CTS must be taught and reinforced from an early age and implemented consistently to enable children to identify various problems, devise solutions, and develop critical thinking skills necessary for meaningful societal engagement [5]. Critical thinking and creativity positively influenced their problem-solving abilities and academic performance; furthermore, their problem-solving skills directly enhanced their academic achievement [6].

Thinking skills are very important for students to master because they are related to problem-solving skills [7]. The correlation between nurses' critical thinking disposition and their ability to solve problems was of a slightly significant level [8]. Positive and significant correlations were found between critical thinking, reflective thinking, and creative thinking, which all predicted academic accomplishment [9]. The findings suggest that, overall, critical thinking has a positive impact on academic achievement, particularly across all examined academic disciplines. MBA students possessing superior critical thinking skills outperform those with average critical thinking skills, who in turn outperform students with inferior critical thinking skills [10]. Problem-solving is fundamental in all scientific fields, as it can uncover critical concepts inherent to those disciplines. Consequently, problem-solving functions as both a prevalent instrument and a sought-after result in numerous science courses [11].

Enhancing advanced cognitive abilities is a primary objective of higher education. It is essential to implement suitable strategies to enhance cognitive levels [12]. Academic achievement can be defined as the level of knowledge and skills acquired by students in academic studies [13]. Academic accomplishment reflects the degree

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to which pupils comprehend and assimilate the instructional content. When students grasp the notion well, it is presumed that they will adeptly navigate daily challenges [14]. Students with strong intellects will develop greater responsibility, independence, courage, and respectability in educational institutions and society.

Immunology is considered to be challenging to comprehend as well as teach due to its intricate systems, interdisciplinary nature, and rapid advancements [15]. Complex systems are defined by numerous interacting components, nonlinear relationships, the emergence of collective behaviors, and the capacity for adaptation and self-organization [16]. Immunology displays all of these attributes. Initially, various components – such as immune cells, antibodies, cytokines, and signalling molecules – engage in complex interactions through detailed networks of signalling pathways, feedback loops, and regulatory mechanisms [17]. Mastering immunology necessitates a comprehensive understanding of various biological disciplines, given its interdisciplinary nature. Understanding the interactions among the diverse cellular and fluid components of the immune system requires extensive knowledge across multiple disciplines, including molecular biology, cell biology, genetics, physiology, anatomy, and biochemistry. The complexity of various levels and systems can pose significant challenges for both students and educators in the field of immunology [18].

Immunology is a significant and central field, yet its complexity creates challenges in teaching and learning [19]. Immunology fulfils two specific educational objectives: (a) training healthcare professionals and immunologists, and (b) enhancing immunological literacy. Thus, a deeper understanding of immunology could enhance the knowledge of these health professionals and, consequently, the medical care they provide to their patients. Studies show that a thorough understanding of vaccination procedures by medical professionals is linked to a greater likelihood of promoting child immunization to parents [20]. Engaging in reasoning concerning immunology-related matters necessitates the use of expertise to analyze media reports pertaining to immunology [21]. 'Immune literacy' denotes the capacity to comprehend and apply immunological information in daily life; 'enhancing immune literacy' pertains to augmenting the understanding of non-professionals who will not pursue careers as health practitioners or immunologists, typically within the framework of compulsory education [22].

Medical Immunology is a comprehensive theory that integrates various medical disciplines, highlighting that immunity can be both advantageous and detrimental to the host, hence necessitating enhanced critical thinking skills among students. Critical thinking equips students with a profound understanding of intricate clinical scenarios [23]. Students must be well-versed in each of these topics to comprehend the immune system. Students require time to thoroughly process, evaluate, and apply all of the material [24]. The notion of immunity emphasizes the duality present in critical thinking, possessing the potential to be both advantageous and detrimental to the host, hence highlighting the necessity of evaluating the complete range of consequences. Students should be enabled to assess situations, experimental outcomes, or therapeutic alternatives and pose profound inquiries, ultimately cultivating the ability to think autonomously and resolve issues effectively [23].

The students' critical thinking proficiency and their capacity to use critical thinking in their reading skills remain inadequate. They remain incapable of determining whether the ideas presented in a paragraph are contradictory due to their incapacity to integrate concepts and develop logical deductions [25]. The critical thinking skills of undergraduate students are deficient. Instructors often employ the lecture technique and fail to equip students with the skills necessary for making sound decisions and effectively resolving problems, despite connecting the content to natural facts or occurrences, resulting in challenges in articulating logical arguments [26].

The final form of self-directed learning discussed in the papers was peer instruction, an active learning technique that enabled students to pose questions and receive feedback from peers throughout the course delivery [27]. In Problem-Based Learning (PBL), the educator assumes the role of a facilitator rather than a lecturer. The facilitator aids groups in developing comprehension and linking concepts by structuring knowledge, guiding investigation, reinforcing grasp of challenging ideas, and providing resources [28]. Utilizing uncertain case scenarios encourages students to explore resources and engage in autonomous knowledge retrieval [29]. It is plausible to assert that problem-solving skills can be efficiently cultivated through PBL, given its intrinsic attributes and approach. Repeated exposure to diverse situations enables learners to master multiple problem-solving approaches, including brainstorming, hypothesis testing, and logical reasoning [30].

Potential drawbacks of Problem-Based Learning (PBL) include ambiguity regarding appropriate learning needs, insufficient depth of information attained, challenges in selecting suitable material, time consumption, lack of commitment within study groups, excessive responsibility, and apprehension about identifying the correct learning needs due to the absence of facilitator guidance [31]. The inadequacy of topic knowledge acquisition has been a significant worry for educators. PBL is less effective than conventional approaches due to its minimal direction approach, which is incompatible with human cognitive architecture [32]. Research indicates that PBL problems have not consistently proven useful. Ineffective PBL issues may hinder students' acquisition of adequate domain knowledge, activation of relevant prior knowledge, and optimal self-direction in learning [33].

Mind maps are a technique for note-taking and organizing thoughts that employs diagrams to visually depict concepts and their interrelationships [34]. A mind map is an application that delivers comprehensible and significant information. The mind-map technique organizes the mind to utilize information rationally and creatively, facilitating the production of mental images. In mind mapping approaches, the central concept is identified, followed by the elucidation of the linear perspective [35]. Utilizing mind maps enables students to succinctly summarize material and swiftly pinpoint essential concepts, allowing them to devote additional time to other significant tasks and facilitating improved retention of information in their memory [34]. Mind maps can function as a tool to assist pupils in organizing ideas throughout the pre-writing phase. Examples

can be offered for pupils to construct hierarchical steps that will assist them in organizing concepts [36].

This study introduces a novel integration of PBL and mind-mapping techniques in immunology education, an approach that has not been extensively explored in previous studies. This study illustrates the combined impact of these methods in assisting students to organize intricate concepts, visualize connections, and improve higher-order thinking, in contrast to earlier studies that utilized these approaches in isolation. The results present detailed evidence of enhancements in particular indicators of critical thinking (apply, evaluate, analyze) and cognitive learning outcomes (creating), shedding light on the dimensions that are most receptive to this integrated pedagogical method.

The integration of PBL and mind-mapping in higher education has significant implications for improving instructional practices and curriculum design, particularly in complex subjects such as immunology. While PBL alone promotes inquiry and problem-solving, students often struggle to organize information and connect concepts across cases. Mind-mapping, as a complementary strategy, provides a visual and metacognitive scaffold that enables students to structure knowledge and reflect on relationships among ideas. Therefore, combining these two approaches may not only enhance students' cognitive learning outcomes but also cultivate their critical and analytical thinking skills that are essential for scientific reasoning.

Research Methods

Research Design

A pre-experimental one-group pretest-posttest design was employed to assess the effects of PBL-assisted mind-mapping on students' critical thinking, problem-solving, and cognitive learning outcomes. The research was conducted in the Department of Biology at the State University of Malang, Indonesia. The study sample comprised 23 students enrolled in the basic immunology course. Participants were selected using purposive sampling, as they represented the intact class where the intervention was implemented. The initial assessment of the group's critical thinking and cognitive learning outcomes was conducted by administering five tests during the inaugural meeting. Following the conclusion of all instructional sessions, a post-test was administered through an essay-based assessment tool. A comparison was made between the post-test and pre-test results to assess the influence of PBL-assisted mind-mapping on students' abilities to think critically, solve problems, and achieve cognitive learning outcomes.

Instruments of The Study

The assessment consisted of a five-item essay test designed to evaluate proficiency in critical thinking and cognitive learning outcomes. The reliability of all instruments was assessed using Pearson's product-moment correlation coefficient and Cronbach's Alpha. The results of the validity and reliability tests suggested that all of the test items demonstrated both validity (Pearson's value>0.5) and reliability (Cronbach's alpha>0.7). The critical thinking assessment consists of 5 critical thinking indicators: apply, evaluate, use data to develop critical insight, analyze, and synthesize [37]. The cognitive learning outcomes consist of 3 indicators: analyzing, evaluating, and creating [38].

Data Collection and Data Analysis

Data on critical thinking and cognitive learning outcomes were collected by administering an essay test to students. The test response was evaluated by considering specific criteria outlined in the chosen rubric. Normality and homogeneity tests were performed using the Kolmogorov-Smirnov and Levene's tests, which showed that all data had a P-value greater than 0.05, indicating statistical significance. The Paired t-test was conducted to analyze the differentiation between before and after the intervention. The effectiveness of the PBL-assisted mind-map in improving critical thinking and cognitive learning outcomes was analyzed through N-gain.

Results and Discussion

The development of analytical reasoning abilities is a fundamental component of education that has been pursued by numerous educators throughout the years, as it is thought to enhance academic success [10]. Mastering critical thinking encourages students to develop the capacity for independent thought, allowing them to critically analyze and address challenging problems, assess various alternatives, and make informed decisions. Additionally, they can evaluate complex systems and information, identify patterns, forecast outcomes, provide guidance, and suggest suitable courses of action [39][10]. Mastering critical skills is essential as an indicator of successful learning within an institution, reflected in academic performance and cognitive learning outcomes.

The study revealed that implementing PBL-assisted mind-mapping significantly enhances students' critical thinking skills and cognitive learning outcomes. Paired t-test analysis results to calculate the significant impact of the PBL-assisted mind-map on students' critical thinking skills and cognitive learning outcomes are displayed in Table 1.

Table 1 shows a significant value for each skill (0.000 and 0.002) < 0.050, indicating that the PBL-assisted mind-map has a significant impact on students' critical thinking skills and cognitive learning outcomes. The Cohen's D test showed that PBL assisted mind-mapping had a large effect in improving students' critical thinking and a very large effect in cognitive learning outcomes.

The increase in critical thinking skills and cognitive learning outcomes following the implementation of the PBL-assisted mind-map is presented in Table 2.

By engaging learners to real-world challenges, PBL enhances their capacity to assess situations, discern pertinent information, and decompose intricate problems into more manageable parts. This process improves their ability to think critically, assess evidence, and make informed decisions—an essential skill set relevant in various fields. This pedagogical method is designed to provide various advantages in enhancing general problem-solving skills and preparing individuals to tackle complex challenges effectively [30]. The problem-solving process involves identifying solutions to particular issues, whereas the implementation phase focuses on applying those solutions to real-world situations that present challenges [12]. Open

dialogue among students and faculty regarding value topics can enhance students' ability to process information related to values, fostering their independent understanding and comprehension of the material concepts. Enhancing self-awareness fosters students' objectivity and enhances their problem-solving skills [40][41].

Table 1. Paired t-test Result

Skills	Paired Differences		T	Df	Sig. (2-tailed)	Effect Size
	Mean	Std. Deviation				
Critical Thinking	-.61739	.40413	-7.327	22	.000	0.89
Cognitive Learning Outcomes	-10.56522	14.79504	-3.425	22	.002	1.6

Table 2. N-gain of Critical Thinking and Cognitive Learning Outcomes

Skills	N	Pre-test	Post-test	N-gain Score	Category
Critical Thinking	22	2.92	3.82	0.45	Moderate
Cognitive Learning Outcomes	22	66.22	76.78	0.31	Moderate

Table 3. N-gain Scores of Critical Thinking Skills Indicators

Indicator	Pre-test	Post-test	N-gain Score	Category
Analyze	75.00	82.50	0.3	Moderate
Apply	50.00	77.25	0.32	Moderate
Synthesize	68.50	81.50	0.23	Low
Use Data to Develop Critical Insight	67.50	83.75	0.45	Moderate
Evaluate	68.50	81.50	0.56	Moderate

Table 3 shows an increase in the average pre-test and post-test scores. The increase in critical thinking and cognitive learning outcomes was in the moderate category, with scores of 0.45 and 0.31, and was interpreted as relatively increased.

Implementing the PBL-assisted mind-map improves critical thinking skills. The improvement is categorized as moderate and interpreted as increased. The improvement in critical thinking skills is accompanied by an increase in each indicator, as measured by N-gain scores. The N-gain scores for each indicator of critical thinking skills after implementing the PBL-assisted mind map are presented in Table 3.

Table 3. shows the N-gain scores of each critical thinking skill indicator. The improvement of analyze, apply, use data to develop critical insight, and evaluate indicators was in a moderate category with N-gain scores of 0,3, 0,32, 0,45 and 0,56 and interpreted as increased. The increase in synthesize indicator was in a low category with N-gain scores of 0,23, which was interpreted as relatively increased. The level of students' critical thinking skills is displayed in Figure 1.

Figure 1 illustrates a significant increase in students' critical thinking skills following the implementation of the PBL-assisted mind map. Figure 1 presents the level of students' critical thinking skills in both the pre-test and post-test stages across five indicators: analyse, apply, synthesise, use data to develop critical insight, and evaluate. The pre-test results indicate that most students were at the proficient level, with only a few achieving the *exemplary* level. Following the intervention, a notable improvement was observed, particularly in the *exemplary* category, across all indicators. For instance, in the post-test, the proportion of students demonstrating exemplary skills in synthesizing and evaluating increased considerably compared to the pre-test. These findings indicate that the applied learning approach effectively enhanced students' critical thinking performance.

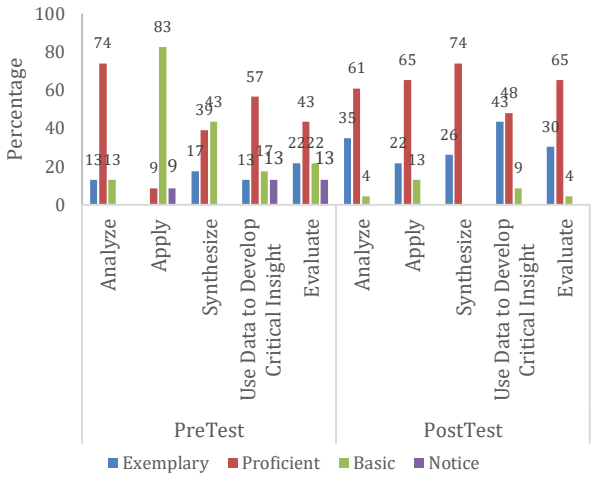

Figure 1. The Level of Students' Critical Thinking Skills

Engaging in small group settings enabled students to engage in more productive discussions. This activity enables students to express their opinions openly, allowing them to focus more on the discussion process and facilitating problem-solving. Notable advancements in education have been observed through the implementation of small-group learning strategies. The small group size enhances the engagement among learners, instructors, and the material being studied. This approach enables educators to anticipate activities and implement strategies that guide learners toward achieving higher levels of cognitive development. In other words, present students with tasks and activities that compel them to engage in cognitive processes like analysis, reasoning, evaluation, and critique [12]. The implementation of PBL has significantly enhanced cognitive skills by enabling students to gain a deeper understanding of concepts and improve their efficacy [42].

Implementing the PBL-assisted mind map improves cognitive learning outcomes, particularly in low categories, and is associated with relatively increased interpretation. The

increasing score of each indicator follows the increasing score of cognitive learning outcomes. The N-gain scores for each indicator of cognitive learning outcomes after implementing the PBL-assisted mind map are presented in Table 4.

Table 4. N-gain of Cognitive Learning Outcomes Indicators

Indicator	Pre-test	Post-test	N-gain Score	Category
Analyzing	62.26	69.57	0.19	Low
Evaluating	79.83	84.00	0.26	Low
Creating	61.39	76.78	0.39	Moderate

Table 4 shows the improvement of each cognitive learning outcome indicator. The creating indicator increase was in a moderate category, with N-gain scores of 0.39, indicating an increase. The improvement in analyzing and evaluating was in a low category, with N-gain scores of 0.19 and 0.26, and interpreted as relatively increased. The level of students' cognitive learning outcomes is displayed in Figure 2.

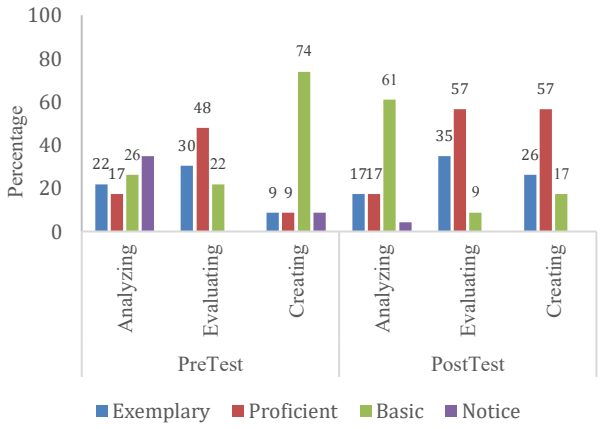

Figure 2. The Level of Students' Cognitive Learning Outcomes

Figure 2 depicts the distribution of students' cognitive learning outcomes across three dimensions—analysing, evaluating, and creating—before and after the intervention. The pre-test results reveal that most students performed at the basic level, particularly in the creating dimension, where 74% of students remained at this category, indicating limited higher-order thinking skills. Conversely, exemplary performance was relatively low across all dimensions. Following the intervention, a significant shift was observed: the proportion of students achieving the exemplary and proficient levels increased substantially across all dimensions. Notably, the percentage of students achieving exemplary outcomes in evaluation and creation rose considerably, while the proportion at the basic level decreased sharply. These findings suggest that the applied instructional strategy was effective in promoting higher-order cognitive processes, thereby advancing students' learning outcomes from predominantly basic understanding toward proficient and exemplary levels of thinking.

Assisting students with PBL by mind-mapping helps them master the basic concepts needed to solve problems. Insufficient understanding and disorganized information necessary for the lesson emerge during the execution of PBL [43]. Mind maps serve as a method for note-taking and production, facilitating the organization of thoughts through keywords, symbols, and images, while also enabling the clustering and summarization of information on a sheet of paper [34]. The integration of mind-mapping with the PBL teaching method significantly enhanced students' proficiency in understanding the subject framework, fostering interdisciplinary connections and improving their clinical problem-solving skills. This approach provided them with greater opportunities for self-development and increased their engagement with the subject matter [44].

Furthermore, mind-mapping facilitates students in making connections between learning materials, helping them improve their analytical skills. Additionally, mind-mapping facilitates the association of ideas, encourages creative thinking, and fosters meaningful connections between concepts [45]. Mind mapping enables a person to see different elements of a complicated task simultaneously in a visual format, which enhances motivation, improves knowledge retention, and fosters creative problem-solving abilities among students [46].

Conclusion

This study demonstrates that integrating Problem-Based Learning (PBL) with mind-mapping techniques significantly enhances students' critical thinking and cognitive learning outcomes in the context of immunology education, a subject widely regarded as complex and interdisciplinary. The findings reveal moderate to substantial improvements in several critical thinking indicators (apply, evaluate, analyze) and cognitive dimensions (creating), underscoring the potential of this combined approach to strengthen higher-order thinking skills and promote deeper conceptual understanding. Despite its promising results, the study has several limitations. The relatively small sample size, single-institution scope, and absence of a control group constrain the generalizability of the findings. In addition, the outcomes were measured in the short term, leaving open the question of whether the observed gains can be sustained over time. Future research should address these limitations by adopting experimental or mixed-method designs, involving larger and more diverse cohorts, and conducting longitudinal studies to assess long-term effects. From a pedagogical perspective, these findings suggest that curriculum designers and educators should consider incorporating structured mind mapping within PBL-based learning environments. Doing so can enhance students' cognitive organization, facilitate deeper learning, and improve engagement in complex scientific subjects. This instructional model can also be adapted for other courses that require high-level integration and reasoning skills.

Author's Contribution

Lianto was responsible for conceptualization, data collection, data analysis, and writing, and Yulista Trias Rohayati was responsible for conceptualization, methodology, data collection, and data analysis.

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