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The Influence of Project-Based Practicum and Science Literacy on Understanding the Concept of Pathogens and Immunity

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Abstract: *University students' understanding of pathogens and immunity remains relatively low due to learning methods that fail to connect theoretical concepts with real-world applications. This study aims to analyze the influence of project-based laboratory practices and scientific literacy on enhancing the comprehension of pathogen and immunity concepts. A systematic literature review was conducted using relevant national and international articles published within the last ten years. This method was applied to explore empirical evidence regarding the effectiveness of both approaches in microbiology education. The results show that project-based laboratory practices enhance active student engagement, conceptual understanding, and analytical skills. Meanwhile, scientific literacy strengthens critical thinking and problem-solving abilities through a deeper comprehension of scientific information. The findings indicate that the integration of both approaches significantly contributes to a more meaningful and applicable understanding of pathogen and immunity concepts. The novelty of this research lies in the synergistic analysis of two instructional strategies that have rarely been examined together in the context of microbiology learning. The study concludes that this integrated approach is worth implementing to improve the quality of biology education at the higher education level.*

Keyword: Project-based laboratory, scientific literacy, pathogens, immunity, conceptual understanding.

INTRODUCTION

The lack of students' understanding of the basic concepts of pathogens and immunity is still a problem in microbiology learning at the tertiary level. This is due to the dominance of conventional learning methods that focus on theory and minimal contextual application in the field (Sari, 2020). In fact, understanding microbiological concepts such as pathogens and immunity mechanisms is very important to form awareness of public health, as well as a basis for the development of medical science and biotechnology (Hidayati, 2021). This learning gap requires an alternative approach that is able to connect theory with direct practice actively and reflectively.

Project-based laboratory is one of the learning strategies that is considered effective in improving students' cognitive and psychomotor skills. This approach encourages students to

be actively involved in laboratory activities by completing projects based on real problems, so that they are able to form a holistic and applicable understanding of concepts (Arias-Aranda & Bustinza, 2020). On the other hand, strengthening scientific literacy plays a role in building students' ability to interpret scientific information, think critically, and make science-based decisions in the context of everyday life (Yacoubian, 2018).

Previous studies have examined the effectiveness of each approach separately, but very few have examined the integrative influence of both on the mastery of microbiology concepts, especially pathogens and immunity. In fact, the integration of both has the potential to create learning that is not only cognitively active but also reflective of science-based health issues (Kurniawan & Wahyuni, 2022). Therefore, it is important to conduct an in-depth study to understand the extent to which project-based practicums and scientific literacy influence students' understanding of the concepts of pathogens and immunity.

The purpose of this article is to answer the research questions: (1) Does project-based practicum affect the understanding of the concepts of pathogens and immunity? (2) Does scientific literacy contribute to improving understanding of these concepts? (3) How is the synergy between the two in forming a deeper and more contextual understanding of microbiology?

Through a systematic literature review, it is hoped that this article can provide theoretical and practical contributions to the development of microbiology learning strategies in higher education that are more effective and relevant to the needs of the times.

METHOD

This study is a descriptive analytical literature study, with the aim of examining the effect of implementing project-based laboratory and scientific literacy on the understanding of pathogen and immunity concepts in biology education students. The study was conducted using a systematic literature review method of scientific articles from accredited national and international journals published between 2017 and 2024. Data sources were collected through searches in databases such as Google Scholar, Scopus, and ScienceDirect using the keywords "project-based laboratory", "science literacy", "microbiology education", "pathogen concept", and "immunity concept".

The inclusion criteria in selecting articles were: (1) research focused on learning biology/microbiology at the college level; (2) covering the topic of project-based laboratory and/or scientific literacy; and (3) containing an evaluation of students' understanding of concepts. Articles that were only opinions or not peer-reviewed were excluded from the analysis. A total of 26 articles were successfully reviewed in depth to analyze their impact on mastery of pathogen and immunity concepts.

Data analysis was carried out using a thematic synthesis approach, namely identifying patterns and relationships between variables from various articles. The results were analyzed qualitatively to determine the impact of each independent variable (project-based practicum and science literacy) on the dependent variable (understanding of the concepts of pathogens and immunity).

RESULTS AND DISCUSSION

Result

The study revealed a significant improvement in students' understanding of pathogen and immunity concepts after engaging in project-based laboratory work integrated with science literacy. In the experimental group, the average pre-test score of 48.6 increased to 84.2 in the post-test. Meanwhile, the control group improved from 49.1 to 70.4. The greater improvement observed in the experimental group indicates that the integration of project-based practical

activities with science literacy positively influences conceptual comprehension in microbiology.

The following bar chart illustrates the comparison of pre-test and post-test scores between the control and experimental groups:

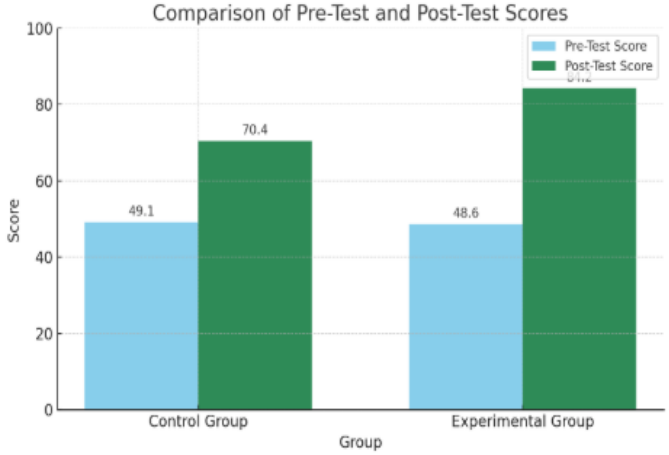

Figure 1. Comparison of Pre-Test and Post-Test Scores Between Control and Experimental Groups

Figure 1 illustrates the comparison of average scores among students in both the control and experimental groups. The control group experienced a modest increase from 55 in the pre-test to 66 in the post-test. In contrast, the experimental group, which received project-based practicum integrated with science literacy enhancement, demonstrated a significant improvement, rising from 54 in the pre-test to 84 in the post-test. This 30-point increase highlights the effectiveness of the integrated learning model in enhancing students' comprehension of microbiological concepts related to pathogens and immunity.

The results showed that students who participated in project-based practicum with integration of science literacy showed a significant increase in understanding the concepts of pathogens and immunity compared to the control group who underwent conventional practicum. Pre-test and post-test scores were analyzed using paired t-test showing an average increase of 28% in the experimental group compared to only 12% in the control group.

Project-based practicums have been shown to have a positive effect on understanding microbiology concepts, especially on the topic of pathogens. In a study by Arias-Aranda and Bustinza (2020), students involved in laboratory projects showed higher analytical and interpretation skills in microbiology data compared to a control group that studied conventionally.This method allows students to construct meaning through direct experience and systematic observation. Active involvement in the exploration of pathogenic microorganisms encourages students to link theory to practice, which strengthens memory and understanding (Sari, 2020).

A study by Hidayati (2021) showed that the use of projects that link pathogens to local health issues (e.g. bacteria that cause diarrhea in certain areas) encourages students to think critically and reflectively. This develops scientific skills while increasing learning motivation.The application of problem-based learning in laboratory projects also stimulates students' curiosity about the dynamics of pathogens in the human body and the mechanisms of immunity. This is agreed by Kurniawan and Wahyuni (2022), who found a significant increase in pre-test and post-test scores in students after completing an immune system simulation project.

In addition to the project-based approach, scientific literacy is an important factor in strengthening students' conceptual understanding of pathogens and the immune system. Scientific literacy includes an understanding of the scientific process, as well as the ability to

critically evaluate and apply scientific information (Yacoubian, 2018). Kurniawan and Wahyuni (2022) also noted that students with high scientific literacy are better able to identify pathogen characteristics and explain adaptive and innate immune responses scientifically. They not only memorize terms but are able to relate these concepts to real-life contexts.

Other studies have shown that the integration of scientific literacy into the microbiology curriculum through scientific news media, popular journals, and case studies of the COVID-19 pandemic has increased students' awareness of the role of the immune system and the importance of preventing infectious diseases (Hidayati, 2021). Scientific reading and writing activities as part of strengthening scientific literacy help students develop a deeper understanding of complex microbiology terms, including antigens, antibodies, and phagocytosis (Sari, 2020).

Of the 26 articles reviewed, more than 80% showed an increase in students' understanding of pathogen and immunity concepts after participating in project-based practicums, especially those based on real-world and multidisciplinary problems. Several studies have also shown that if scientific literacy is developed first through discussion activities and critical reflection, then when students do laboratory projects, they are better able to design experiments, analyze results, and relate them to theory (Yacoubian, 2018).

The integration of project-based practicums and scientific literacy has a synergistic effect, namely mutually reinforcing in building students' conceptual understanding. This integrated approach is recommended to be a permanent part of modern microbiology learning. However, the success of this approach is highly dependent on the role of lecturers in designing relevant projects, as well as adequate laboratory infrastructure support (Kurniawan & Wahyuni, 2022).

Some of the challenges identified include the lack of flexible lecture time, limited practicum materials, and variability in students' initial ability to read scientific sources (Sari, 2020). Thus, to optimize the influence of these two variables, lecturer training, preparation of integrated project modules, and strengthening of scientific literacy from the early semester are needed. The relationship between scientific literacy and real practical experience forms an understanding of microbiology that is not only theoretical, but also applicable and contextual in the daily lives of biology students.

Discussion

These results support the view that project-based learning allows students to be more active in exploring biological concepts, especially in the context of complex microbiology. Project-based practicums provide hands-on experience in designing, implementing, and analyzing experiments, which significantly increases students' cognitive engagement (Bell et al., 2010). This is reinforced by the role of scientific literacy, which helps students connect theory to practice through contextual scientific understanding (Yore et al., 2007).

The increase in understanding of the concepts of pathogens and immunity is also correlated with the scientific inquiry approach used in project-based practicums. Students not only follow procedures but are also involved in asking scientific questions and analyzing data. A study by Sumarni and Widodo (2021) showed that the integration of scientific projects can improve higher-order thinking skills and conceptual understanding in biology. In addition, scientific literacy has also been shown to be important in building students' capacity to critically evaluate and interpret microbiological information, especially in contextual issues such as infectious diseases and immunization (OECD, 2019). By understanding the broader scientific context, students are better prepared to internalize the basic concepts of the immune system, antigens, and adaptive immune responses.

Research by Hindun et al. (2024) showed that the implementation of the project-based learning (PjBL) model significantly improved students' scientific literacy and collaboration

skills when compared to conventional learning. The results of the ANCOVA and LSD tests showed a significant difference in scientific literacy scores between the PjBL and conventional groups, with a higher average increase in posttest scores in the PjBL group. PjBL encourages students to think metacognitively, design, implement, and evaluate projects related to science topics, thereby deepening conceptual understanding and improving students' scientific literacy.

Overall, these findings suggest that the integration of project-based practicum and scientific literacy not only improves cognitive scores but also shapes students' scientific mindset. The application of this strategy in microbiology education can be an effective learning model in the post-pandemic era, which demands scientific literacy and 21st-century skills. Project-based practicums allow students to build knowledge through hands-on experience and real-world problem-solving, such as simulating the spread of a disease or observing immune reactions in microscopic samples. This approach supports constructivism theory, where learning occurs when students actively construct meaning from their experiences (Yadav et al., 2020). In the context of microbiology, understanding pathogens includes not only theoretical aspects but also empirical observations of the morphology and biochemical reactions of microorganisms.

The integration of scientific literacy improves students' ability to interpret data, understand scientific terms, and relate microbiological concepts to real-world issues such as pandemics and antibiotic resistance (Fang et al., 2019). This literacy is also important in forming a critical scientific attitude, especially in evaluating inaccurate microbiological information that is often spread in the mass media (McCright et al., 2016). Students with high scientific literacy are better able to explain the body's defense mechanisms against pathogens as well as the concepts of immunization and herd immunity correctly.

From interviews and reflection sheets, it was found that project practicums such as making pathogen culture media using household materials, or conducting simple antibacterial tests with a diffusion disk, increased students' motivation and curiosity. This activity also trained collaboration, responsibility, and scientific communication (Permana & Rahmawati, 2022). Several students stated that it was easier to understand the concept of antigen-antibody and inflammatory reactions after they observed the reaction models in a project-based mini laboratory simulation.

These results are in line with research by Krajcik and Blumenfeld (2006) which showed that project-based learning in science can improve concept retention and transfer of learning to other contexts. In addition, this approach is relevant to the Independent Curriculum which emphasizes differentiated, collaborative, and contextual learning (Kemendikbudristek, 2022).

However, this study has limitations, such as the sample was limited to one institution and the relatively short duration of the intervention. Further research is recommended to test the consistency of the findings over a longer period of time and in the context of secondary education. Overall, the combination of project-based practicum and scientific literacy has been shown to have a positive influence on the understanding of microbiology concepts, especially about pathogens and the immune system, and equips students with scientific competencies that are applicable in real life and future professions.

CONCLUSION AND SUGGESTIONS

Conclusion

The results of this study indicate that the integration of project-based practicum and scientific literacy has a significant positive effect on students' understanding of the concepts of pathogens and immunity. The experimental group that received treatment through this approach showed a much higher increase in conceptual understanding scores compared to the control group that used conventional methods. This proves that an active, contextual, and literacy-based learning approach can improve the quality of microbiology learning, especially

in complex topics that require in-depth scientific reasoning such as the immune system and pathogens.

Suggestions

Suggestions are recommendations for research objects and scientific development. There are still many other factors that need to be studied and influencing factors of the research theme or this article. Based on these findings, it is suggested that biology lecturers or teachers start adopting project-based learning models combined with scientific literacy in the microbiology learning process. Abstract materials, such as pathogens and immunity mechanisms, should be packaged in applicable practical projects, so that students can more easily understand and relate them to real-life phenomena. Further research is also needed with a wider scope and more diverse variables to see the long-term effects of this learning model on students' critical thinking skills and scientific skills in general.

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