



The influence of problem-based learning with socio-scientific issues on improving concept mastery and critical thinking in biotechnology

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Abstract

The low conceptual mastery and critical thinking skills of grade 10 students in biotechnology create a need for a more contextual and meaningful learning model. This study aims to determine the effect of the Problem-Based Learning (PBL) model integrated with Socio-Scientific Issues (SSI) on conceptual mastery and critical thinking skills in biotechnology. The study used a quasi-experimental design with two groups: an experimental class using PBL integrated with SSI and a control class using the Discovery Learning model. Data were collected through pre-tests and post-tests using multiple-choice questions for conceptual mastery and essays for critical thinking skills. The research results show that the experimental class had an average conceptual mastery score of 85, which was higher than the control class's score of 67. For critical thinking skills, the experimental class obtained an average score of 81, while the control class scored 74. The MANOVA statistical test yielded $p < 0.05$, indicating that the PBL-SSI model had a significant effect on conceptual mastery and critical thinking skills. N-Gain analysis showed a high increase in the experimental group and a moderate increase in the control group. This indicates that integrating PBL with SSI creates a meaningful learning environment, promoting better conceptual understanding and critical thinking skills. The impact of this study is expected to serve as a reference for developing innovative learning methods in future biology education.

Abstrak. Keterampilan penguasaan konsep dan berpikir kritis siswa kelas 10 dalam bioteknologi yang rendah menciptakan kebutuhan akan model pembelajaran yang lebih kontekstual dan bermakna. Penelitian ini bertujuan untuk menentukan pengaruh model Pembelajaran Berbasis Masalah (PBL) yang terintegrasi dengan Isu-Isu Sosial-Ilmiah (SSI) terhadap penguasaan konsep dan keterampilan berpikir kritis dalam bioteknologi. Penelitian ini menggunakan desain quasi-eksperimental dengan dua kelompok: kelas eksperimen yang menggunakan PBL terintegrasi dengan SSI dan kelas kontrol yang menggunakan model Pembelajaran Penemuan. Data dikumpulkan melalui tes awal dan tes akhir menggunakan soal pilihan ganda untuk penguasaan konsep dan esai untuk keterampilan berpikir kritis. Hasil penelitian menunjukkan bahwa kelas eksperimen memiliki skor rata-rata penguasaan konsep sebesar 85, yang lebih tinggi daripada skor kelas kontrol sebesar 67. Untuk keterampilan berpikir kritis, kelas eksperimen memperoleh skor rata-rata 81, sementara kelas kontrol mendapatkan skor 74. Uji statistik MANOVA menghasilkan $p < 0.05$, menunjukkan bahwa model PBL-SSI memiliki dampak signifikan terhadap penguasaan konsep dan keterampilan berpikir kritis. Analisis N-Gain menunjukkan peningkatan tinggi pada kelompok eksperimen dan peningkatan moderat pada kelompok kontrol. Hal ini menunjukkan bahwa integrasi PBL dengan SSI menciptakan lingkungan belajar yang bermakna, yang mempromosikan pemahaman konseptual yang lebih baik dan keterampilan berpikir kritis. Dampak penelitian ini diharapkan dapat menjadi acuan untuk mengembangkan metode pembelajaran inovatif dalam pendidikan biologi di masa depan.

A. Introduction

Conceptual understanding refers to students' ability to comprehend scientific meaning deeply, both theoretically and in real-life contexts (Dahar, 2006). In the educational process, this understanding serves as a primary goal and an essential indicator of learning success, as it enables students not only to master the material but also to connect it with their prior knowledge (Sintiawati et al., 2021).

Low conceptual mastery often occurs because teaching methods are still too focused on the teacher's role as the transmitter of material, causing students to be less active in the learning process (Gholam, 2019). Another contributing factor is the limited availability and lack of interest in learning resources, such as textbooks that are unappealing and scarce (Tampubolon et al., 2015).

Yustiqvar et al. (2019) argue that conceptual understanding influences students' critical thinking skills, where higher conceptual mastery correlates with improved critical thinking abilities. According to Suryanda et al. (2020), critical thinking and conceptual understanding are essential for students to develop their knowledge, especially since they often face real-life problems in society. Students with strong conceptual understanding tend to have more developed critical thinking skills (Fauziah, 2017). Amijaya et al. (2018) explain that limited conceptual understanding affects students' ability to integrate information and conduct analysis, thereby hindering the development of their critical thinking skills. Pamungkas et al. (2018) found that critical thinking skills in Indonesia remain low, particularly in evaluation, inference, and problem-solving strategies, with results below 20%.

The low level of critical thinking skills is caused by learning models that fail to provide opportunities for active student participation and instead rely on one-way information delivery with limited discussion (Surayya et al., 2014). Critical thinking can develop through both cognitive abilities and continuous training (Stanley & Moore, 2013), explains why students in the same classroom may demonstrate varying levels of critical thinking skills.

Problem-Based Learning is an effective model that promotes conceptual understanding through active problem solving. Problem-Based Learning encourages collaboration and joint problem solving and has been proven to improve cognitive learning outcomes (Mardiana, 2016). Thus, PBL influences both students' conceptual understanding and their level of critical thinking.

However, the implementation of PBL so far has not sufficiently focused on the nature of the problems presented. According to Jonassen and Hung (2008), research exploring the characteristics of problems in PBL is relatively scarce compared to other aspects of PBL. Problems are usually designed based on theoretical principles, experience, and prior

knowledge (Sockalingam & Schmid, 2011), but they often lead students toward a single solution. This limits students' ability to think broadly. Therefore, problems need to be presented in ways that encourage students to master concepts more deeply and approach them from multiple perspectives.

Problem-Based Learning is widely implemented, both in educational practice and research. According to Wicaksono (2020), biotechnology is a multidisciplinary and applied field that requires accurate conceptual mastery. To keep biotechnology teaching relevant, it is important to integrate not only conceptual theory but also real-world social issues to encourage students' critical thinking about the ethical, economic, and social implications of biotechnology applications.

Problem-based learning is most effective when combined with SSI that involve ethical, social, and cultural considerations (Husniyyah et al., 2023). SSI refers to controversial social issues related to science (Fibonacci, 2020), aimed at stimulating intellectual, moral, and ethical development, as well as awareness of the relationship between science and social life. SSI are real-world issues that are conceptually related to science but have open-ended solutions (Wilsa et al., 2017). SSI often involve scientific uncertainty and social dimensions, making them highly relevant for classroom discussions (Tosunoglu & Lederman, 2021). In Indonesia, with its diverse ethnic, religious, and cultural background, integrating SSI is particularly relevant (Sadler, 2017).

This study is also driven by concerns in international education. The results of the Programme for International Student Assessment (PISA) indicate that Indonesian students still lag behind in critical thinking and conceptual understanding compared to global standards (OECD, 2018). In the context of the Fourth Industrial Revolution, critical thinking and scientific literacy are globally essential skills (OECD, 2017). Therefore, there is a need for a learning model that can simultaneously enhance both conceptual understanding and critical thinking, particularly one that integrates real-world socio-scientific issues to prepare students for global challenges while strengthening the competitiveness of Indonesian education at the international level.

Although many studies have examined the effectiveness of PBL in improving conceptual understanding and critical thinking, few have focused on the types of problems used in PBL and their integration with SSI. Most existing research presents problems from a limited perspective, reducing opportunities for broader critical analysis. Studies that apply PBL integrated with SSI in the context of biotechnology are still rare, despite the subject's strong demand for multidisciplinary and real-life applications (Sockalingam & Schmid, 2011). Therefore, this study aims to analyze the effect of PBL

integrated with SSI on students' conceptual understanding and critical thinking skills in biotechnology learning, representing the novelty and main contribution of this research. Specifically, this study seeks to determine whether the implementation of the PBL-SSI model can significantly enhance students' conceptual understanding and critical thinking abilities.

B. Material and method

This study uses a quasi-experimental approach with a Pretest-Posttest Control Group Design. This design is employed to examine the effect of the PBL model integrated with SSI on students' conceptual mastery and critical thinking skills. The study was conducted in the even semester of the 2024/2025 academic year, specifically from April to June 2025 at SMAN 5 Baubau, Southeast Sulawesi. The entire learning process in both classes was taught by the researcher themselves to ensure consistency of treatment and minimize the influence of differences in teaching styles on the research results.

Sample selection was conducted using a multi-stage sampling technique. First, purposive sampling was applied, selecting students from SMAN 5 Baubau. Second, cluster random sampling was used to obtain students from classes X.1 and X.2, totaling 69 students. The minimum sample size was determined using Slovin's formula with a 5% precision level, resulting in 59 students. Then, using simple random sampling, 30 students from class X.1 were chosen as the experimental group and 29 students from class X.2 as the control group. The Discovery Learning model was selected as a comparison because it is a commonly used teaching approach at the school where the research was conducted and is part of the applicable teaching standards. This model was also chosen because it allows for a more balanced comparison with PBL-SSI, as both approaches are student-centered.

The data collection instruments consisted of a multiple-choice test to measure conceptual mastery of biotechnology and an essay test to assess critical thinking skills based on Facione's (2015) indicators. The validity of the multiple-choice test used to measure concept mastery was analyzed using the point-biserial correlation, with 20 out of 25 items deemed valid. Its reliability was calculated using KR-20, yielding a value of 0.80, which is considered high.

For the critical thinking essay test, validity was analyzed using the Pearson Product Moment correlation, with 7 out of 8 items found to be valid. Its reliability was calculated using Cronbach's Alpha, resulting in a value of 0.82, also classified as high. These results indicate that the instruments used were valid and reliable for measuring the research variables.

The data were analyzed quantitatively using descriptive and inferential statistics, including normality tests, homogeneity tests, and linearity tests. Hypothesis testing was conducted using MANOVA (Multivariate Analysis of Variance) to determine the effect of the treatment on two dependent variables. N-Gain scores were used to measure the extent of student's improvement in understanding after the learning process. In addition, since this study was conducted in only one school with a limited sample size, generalizing the results to a broader population should be done with caution. Student characteristics, the school environment, and other local factors may influence the applicability of the research findings.

C. Results and discussion

The results of the study indicate that the implementation of the PBL model integrated with SSI has a significant effect on improving students' conceptual understanding and critical thinking skills in biotechnology material.

The average score in the experimental class using the PBL model integrated with SSI reached 85, while the control class using the Discovery Learning model had an average score of 67 (see Table 1). In addition to the difference in average conceptual understanding scores, the minimum and maximum scores in both classes also showed differences in learning outcomes. This indicates that students in the experimental class using the PBL-SSI learning model demonstrated more significant results compared to students using the Discovery Learning model.

The effectiveness of the PBL-SSI model in enhancing conceptual understanding is reinforced by the contextual learning experience students gain when solving problems based on SSI. This aligns with the findings of Norman and Schmidt (2010), who stated that PBL provides broader opportunities for exploration, enabling the development of deeper and more applicable scientific understanding.

Table 1 Descriptive statistics of concept mastery

Data	PBL-SSI	Discovery learning
Minimum	75	55
Maximum	95	75
Average	85	67
Standard deviation	6	6
N	30	29

Table 2 Average conceptual understanding scores by dimension in the experimental and control classes

Dimension	PBL-SSI	Discovery learning
Factual and procedural knowledge	98	90
Connection	90	83
Knowledge transfer	66	55
Metacognition	74	46

Table 3 Descriptive statistics of critical thinking skills

Data	PBL-SSI	Discovery learning
Minimum	72	50
Maximum	95	82
Average	81	74
Standard deviation	6	6
N	30	29

Table 4 Average critical thinking scores by dimension in the experimental and control classes

Dimension	PBL-SSI	Discovery learning
Interpretation	89	71
Evaluation	95	75
Self-regulation	94	77
Inference	93	73
Explanation	96	68
Analysis	98	79

Table 5 Hypothesis test results and N-Gain analysis

Variable	P-value	Group	Mean	Std.Dev
Concept mastery	0.000	Experimental	76.20	2.20
		Control	63.59	4.49
Critical thinking	0.000	Experimental	82.10	2.33
		Control	61.72	4.04

Improvements in conceptual understanding can also be seen across the four dimensions (Table 2) of conceptual knowledge as outlined by Mills (2016), with the factual and procedural knowledge dimension showing the highest increase. This indicates that students not only recall information but also comprehend the steps and scientific processes, such as those involved in conventional biotechnology learning (e.g., fermentation). Meanwhile, the improvements in the connection and knowledge transfer dimensions demonstrate that students are able to relate concepts to real world contexts, although the transfer dimension still requires reinforcement. The metacognitive dimension showed the lowest increase. The metacognitive dimension showed the lowest improvement in the experimental class, indicating that the PBL-SSI model has not yet been fully effective in developing students reflective thinking skills. This may be due to the lack of explicit steps in the model that directly train metacognitive skills, such as planning, monitoring, and evaluating the thinking process. Therefore, it is necessary to incorporate explicit components into the PBL-SSI model, such as reflection guides and targeted teacher facilitation, to strengthen students' metacognitive dimension (Gredler, 2008).

The conceptual understanding outcomes obtained in both the experimental class, which implemented the PBL-SSI model, and the control class, which applied the Discovery Learning model, show a noticeable difference. This difference can be seen in the comparison between the experimental and control classes. The control class using the Discovery Learning model engaged students in developing and presenting their observations on the given problems (Putri et al., 2019). However, the outcomes were still not as strong as those of the experimental class. The PBL-SSI model enables students to gain a deeper understanding of concepts, as they not only solve problems but also analyze social issues, make decisions, and reflect on the scientific and societal impacts of the discussed topics (Tasonglu & Bakac, 2014). Therefore, it can be concluded that learning biotechnology using the PBL-SSI model has a significant influence on improving students conceptual understanding.

The average scores in both the experimental and control classes indicate differences in students critical thinking skills (Table 3). The average score in the experimental class using the PBL model integrated with SSI reached 81, while the control class using Discovery Learning scored an average of 74. In

addition to the average scores, the minimum and maximum values also show a disparity in learning outcomes between the two classes. This indicates that students in the experimental class using the PBL-SSI model achieved more significant results than those in the control class.

A clear improvement in critical thinking skills can be observed across all six indicators (Table 4) as defined by Facione (2015): interpretation, analysis, inference, evaluation, explanation, and self-regulation. The highest improvement was seen in the analysis dimension, where students were able to identify and solve contextual problems through scientific approaches. This is supported by Wahyuni (2024), who stated that PBL promotes the development of deeper analytical skills.

The inference and evaluation dimensions also showed significant improvement, as students became accustomed to evaluating various perspectives when addressing socio-scientific problems. Discussion and presentation activities developed within the PBL-SSI model contributed to the enhancement of the explanation dimension, while self-regulation improved as students were trained to design their own learning strategies and engage in self-reflection.

Overall, the average results across each dimension indicate that learning through the PBL-SSI model is more effective in developing students' critical thinking skills comprehensively compared to the Discovery Learning model. Each indicator showed improvement, although the degree of improvement varied depending on the complexity of the dimension and the extent to which the learning activities promoted students' cognitive engagement.

Although the control class also experienced improvements across all dimensions of critical thinking skills, the results were not as significant as those in the experimental class. This may be attributed to the Discovery Learning model, which emphasizes independent exploration without the strong social and contextual stimuli present in the PBL-SSI approach. Discovery Learning places less emphasis on deep reflective and evaluative activities, thereby limiting the development of students' critical thinking skills. Thus, the average results indicate that the PBL-SSI model is more effective in enhancing students' critical thinking skills comprehensively compared to the Discovery Learning model. This finding aligns with Herzon et al. (2018), who stated that the PBL-SSI model has a significant influence on critical thinking skills and is capable of integrating those skills into various aspects of academic competence. Wilsa et al. (2017) also argued that the implementation of PBL-SSI is superior to conventional learning, as evidenced by the higher average scores in the experimental class compared to the control class.

These findings are consistent with other studies, such as those by Suhirman and Khotimah (2020), who reported that the PBL model has a

significant impact on students' critical thinking skills. This underscores the importance of implementing effective learning models to improve the quality of education in schools. Furthermore, this aligns with the findings of Evagorou et al. (2012), which demonstrated differences in higher-order thinking skills between students exposed to treatment models like Discovery Learning and those who were not. The integration of SSI significantly enhances students' higher-order thinking abilities and shows a positive effect on learning outcomes.

Affandy et al. (2019) emphasized that critical thinking skills involve self-regulation in decision-making, encompassing interpretation, analysis, evaluation, and inference, as well as explanation using evidence, concepts, methodologies, criteria, or contextual considerations that form the basis for drawing conclusions or making statements. Critical thinking is an intellectual potential that can be developed through learning processes, such as the PBL model integrated with SSI.

Based on the simultaneous hypothesis testing using MANOVA (Multivariate Analysis of Variance) shown in Table 5, the p-value obtained is less than 0.005. This indicates that the PBL-SSI model is more effective in improving students' conceptual understanding through direct involvement in solving contextual problems related to real-life situations. Additionally, students' critical thinking abilities also show significant improvement because, during the learning process, students are able to analyze information, evaluate arguments, and draw conclusions from multiple perspectives (Sanjaya, 2010). This finding aligns with Azizah et al. (2021), who reported that the PBL-SSI model positively influences students' learning outcomes compared to conventional learning models.

Normalized Gain (N-Gain) is used to measure the extent of students' improvement in understanding after the learning process. Based on the analysis presented in Table 5, it is evident that the experimental group showed higher gains in both conceptual mastery and critical thinking skills compared to the control group. The average N-Gain score for the experimental group falls into the high category, while the control group's score is classified as moderate. This indicates that the implementation of the PBL model integrated with SSI has a greater positive impact on students' learning outcomes (Zaidah et al., 2023). With this approach, students are not only encouraged to develop a deep understanding of concepts but also to enhance their critical thinking skills through active involvement in solving contextual problems. Therefore, the PBL-SSI model proves to be more effective compared to the Discovery Learning model.

However, this study has limitations because it does not consider external factors that may affect students' learning outcomes, such as initial motivation,

prior knowledge, and access to learning resources outside the classroom. These factors were neither measured nor controlled in this study, so their influence on the improvement of conceptual understanding and critical thinking skills cannot be determined. Therefore, future research is recommended to control these external variables in order to obtain a more comprehensive understanding of the effectiveness of the PBL-SSI learning model.

D. Conclusion

Based on the research findings, it can be concluded that the implementation of the PBL model integrated with SSI has a significant impact on improving conceptual understanding and critical thinking skills in biotechnology within the biotechnology course. This model has proven to be more effective compared to conventional teaching methods, as evidenced by the higher average scores in the experimental class compared to the control class. The implications include strengthening curriculum design oriented toward 21st-century learning and the need for teacher training to develop learning that fosters scientific literacy and social awareness. Conceptually, this study contributes scientifically by reinforcing evidence that integrating socio-scientific contexts into problem-based learning can serve as an effective pedagogical approach to develop students' conceptual mastery and higher-order thinking skills.

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