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The Effect of Ethnobotanical Project Based Learning -STEM Model on Students 21st Century Thinking Skills in Science Learning

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Abstrak

Penelitian ini bertujuan untuk mengetahui pengaruh model project based learning-STEM bermuatan etnobotani terhadap keterampilan berpikir kritis siswa dalam pembelajaran IPA. Jenis penelitian ini adalah penelitian meta-analisis. Kriteria inklusi dalam penelitian ini yaitu penelitian harus relevan; data penelitian diperoleh dari Google Scholar, Mendeley, ScienceDirect, ERIC dan ProQuest; Penelitian harus terindeks SINTA atau Scopus, Penelitian terbitan tahun 2023-2025 dan memiliki data yang lengkap untuk memperoleh nilai effect size. Analisis data dengan bantuan aplikasi Jamovi untuk menghitung nilai effect size, bias publikasi dan uji homogenitas. Hasil penelitian ini menyimpulkan bahwa nilai summary effect size (d = 1.129 ; p < 0.005 ; Z = 9.890). Temuan ini menjelaskan bahwa adanya pengaruh model project based learning-STEM bermuatan etnobotani terhadap keterampilan abad-21 siswa dalam pembelajaran biologi dibanding model konvensional ketegori effect size kuat.

Kata Kunci: Project Based Learning; STEM; Etnobotani; Kemampuan abad-21; IPA

Abstract

This study aims to determine the influence of ethnobotanically charged project-based learning-STEM models on students' critical thinking skills in biology learning. This type of research is a meta-analysis research. The inclusion criteria in this study are that the research must be relevant; research data was obtained from Google Scholar, Mendeley, ScienceDirect, ERIC and ProQuest; Research must be indexed by SINTA or Scopus, research published in 2023-2025 and have complete data to obtain effect size values. Data analysis with the help of the Jamovi application to calculate the effect size value, publication bias and homogeneity test. The results of this study concluded that the value of the summary effect size (d = 1.129; p < 0.005; Z = 9.890). These findings explain that there is an influence of the ethnobotanically charged project-based learning-STEM model on students' 21st-century skills in Science Learningcompared to the conventional model with a strong effect size category.

***Keywords**: Project Based Learning; STEM; Ethnobotany; 21st-century capability; IPA*

Introduction

Science learning has a fundamental role in human life, covering various aspects such as health, the environment, biotechnology, and the sustainability of natural resources (Yalçın & Öztürk, 2022; Wilis et al., 2023). As a science that studies living things and their interactions with the environment, Biology contributes to the development of medical technology, biotechnology-based agriculture, and biodiversity conservation(Tuong et al., 2023; Khafah et al., 2023). In healthcare, the understanding of genetics and microbiology has driven innovation in precision medicine and genetic engineering. Meanwhile, in the environmental sector, Biology plays a role in climate change mitigation, ecosystem management, and sustainable use of biological resources(Tiengyoo et al., 2024; Toptas et al., 2024). Therefore, a deep mastery of the concept of Biology is crucial for the younger generation so that they are able to adapt to developments science and technology that is getting more and more rapid (Khafah et al., 2023; Wijayanto et al., 2023).

However, learning science learning in the era of the Industrial Revolution 4.0 and towards the Industrial Revolution 5.0 faces various complex challenges (Rizaldi et al., 2020). The Industrial Revolution 4.0, which is characterized by automation, artificial intelligence (AI), and big data, demands a more innovative, technology-based, and problem-solving-based approach to learning(Suyato et al., 2024; Sholihah et al., 2025; Salcedo et al., 2023). Meanwhile, the Industrial Revolution 5.0 emphasizes the balance between technology and human values, so that Science Learningmust be able to integrate STEM-based approaches with social and ethical aspects in its application(Baran et al., 2021). Learning models that are still dominated by conventional methods tend to be less effective in equipping students with 21st-century skills, such as critical thinking, creativity, communication, and collaboration (Cantaş, 2024).

Furthermore, 21st century skills are essential competencies that must be developed in Science Learningso that students are able to face global challenges(Suwistika et al., 2024; Nihlah et al., 2024). Critical thinking is needed to analyze biological phenomena in depth, interpret experimental data, and relate biological concepts to real problems. Meanwhile, creativity plays a role in finding innovative solutions to environmental, health, and biotechnology challenges, for example in genetic engineering or sustainable ecosystem management(Ningtyas et al., 2024; Rais et al., 2021). In an increasingly complex world, learning Biology not only aims to understand theory, but also encourages students to be able to apply their knowledge in daily life through a problem-solving and scientific exploration-based approach (Priyambodo et al., 2023).

In addition to critical thinking and creativity, collaboration and communication skills also have an important role in learning Biology in the modern era. Biological Sciences are multidisciplinary, so collaboration between students in research-based projects will train them to work in teams, share roles, and integrate different scientific perspectives(Twaddle & Smith, 2020). Good communication skills are necessary to convey scientific ideas clearly, both in oral and written form, so that students can actively participate in academic discussions and present research results effectively (Zainil et al., 2022).

However, the problem is that Science Learningin many educational institutions is still dominated by conventional methods that are teacher-centered, such as lectures and concept memorization, so that it does not provide enough space for students to develop 21st-century skills (Ichsan et al., 2023a). This approach often does not stimulate critical thinking, creativity, collaboration, and communication because students are simply passive recipients of information without the opportunity to explore and apply science learning concepts in real-life situations (Zulyusri, Elfira, et al., 2023a). In fact, global challenges such as climate change, food security, and biotechnology innovation demand individuals who are able to think analytically and find innovative solutions(Wijayanto et al., 2023). Limitations in the use of more interactive and project-based learning models lead to low student involvement in the learning process as well as their lack of ability to apply theory into practice relevant to daily life. In addition, Science Learningcurrently still rarely integrates

aspects of local wisdom, such as ethnobotany, which can provide a learning context closer to students' lives. In fact, ethnobotany as a study of the use of plants by local communities can be a relevant learning medium to understand the concept of Biology in a more applicative and contextual way (Zulyusri et al., 2023b; Oktarina et al., 2021)

The integration of ethnobotany in STEM-based learning through the Project-Based Learning (PBL) model can be a solution to improve students' 21st-century skills by linking the science of Biology (Wilis et al., 2023). Project-Based Learning (PBL) is a project-based learning model that emphasizes the active involvement of students in solving real problems through the process of investigation, collaboration, and reflection(Tiengyoo et al., 2024; Perdana et al., 2021). PBL is closely related to the STEM (Science, Technology, Engineering, and Mathematics) approach, because both are oriented towards the development of authentic and integrative problem-solving-based skills (Rais et al., 2021). In STEM-based PBL, students not only understand science concepts theoretically, but also apply them in the context of technology, engineering, and mathematics to come up with innovative solutions(Marthaliakirana et al., 2022). This approach provides a more meaningful learning experience because it connects different disciplines in a single project that fits into the real world, so students can see the relevance of Biology science to various other fields (Atabey & Topçu, 2020).

The main advantage of Project Based Learning-STEM is its ability to develop ^{21}st-century skills, such as critical thinking, creativity, collaboration, and communication(Atabey & Topçu, 2020; Baran et al., 2021). Through challenging projects, students are trained to analyze problems in depth, design science and technology-based solutions, and work in teams to solve complex tasks. In addition, PBL-STEM also encourages students to develop good communication skills, both in oral and written form, when they have to present the results of their projects. This approach also increases learning motivation, as students feel in control of their own learning process and can relate the knowledge learned to real-life situations(Asadbeigi et al., 2014). Thus, PBL-STEM is an effective strategy in equipping students with the skills needed to face challenges in the era of the Industrial Revolution 4.0 and 5.0 (Bahmani et al., 2016).

Furthermore, the project-based learning-STEM model can be integrated with ethnobotany. Ethnobotany is a field of science that studies the relationship between humans and plants, including how local communities use plants for daily needs, such as medicines, food, and cultural rituals(Jarić et al., 2015). In the context of learning Biology, the integration of ethnobotany can provide a more contextual understanding of biodiversity, ecology, and natural resource conservation. By including ethnobotany content in the STEM-based Project-Based Learning (PjBL) model, students not only learn the concept of Biology theoretically, but also understand how the science is applied in people's lives(Asadbeigi et al., 2014). This approach can increase students' environmental awareness, as they are invited to explore and document local knowledge about plants and their impact on ecosystems. In addition, the integration of ethnobotany in PBL-STEM also encourages students to think critically about biodiversity conservation and sustainable use of biological resources, so that they are better prepared to face global challenges in the field of ecology and biotechnology (Turner & Turner, 2008; Hussim et al., 2024)

Research by Atabey & Topçu, (2020); Oktay et al., (2020); Han et al. (2015) shows that the application of PjBL-STEM in science learning can increase student engagement, concept understanding, and creativity in solving STEM-based challenges. These studies indicate that project-based learning combined with STEM approaches not only improves understanding of science concepts, but also builds the collaborative and communication skills needed in the era of the Industrial Revolution 4.0. Research by Setyawati et al. (2020) found that integrating ethnobotany in science learning can increase students' understanding of the concept of biodiversity and build their awareness of the importance of local plant conservation. Another study conducted by Ramadhani et al. (2021) showed that the use of ethnobotanical content in project-based learning not only enriched students' insights into local wisdom, but also improved their critical thinking

skills and ability to relate Biology concepts to real life. Although previous research has shown the effectiveness of Project Based Learning (PBL) and STEM models in improving students' 21st century thinking skills, as well as the potential of ethnobotany in the context of biology learning, there are still clear research gaps. Existing research often focuses on the application of PBL-STEM in general, without integrating specific ethnobotanical contents. In addition, meta-analyses that specifically examine the influence of ethnobotanically charged PBL-STEM models on students' 21st century thinking skills in Science Learningare still very limited. Therefore, this study aims to fill the gap by conducting a comprehensive meta-analysis, in order to provide strong empirical evidence regarding the effectiveness of this innovative learning model in the context of science learning.

Method

Design Research

This study uses a meta-analysis approach to determine the influence of ethnobotanically charged project-based learning-STEM models on students' critical thinking skills in biology learning. Meta-analysis is a research approach that evaluates previous research statistically to reach a conclusion (Tamur et al., 2020); (Badawi et al., 2023; Edy Nurtamam et al., 2023; Zulyusri, Santosa, et al., 2023; Ali et al., 2024.; Ichsan et al., 2023). The meta-analysis research procedure is 1) determining the research inclusion criteria, 2) collecting data and coding, 3) analyzing the data statistically.

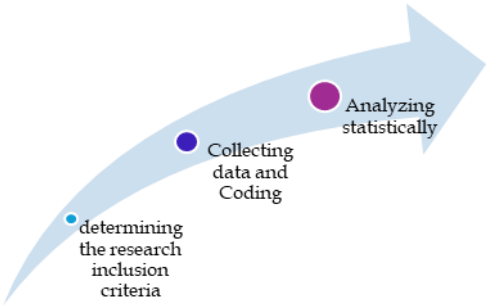

Figure 1. Meta-analysis Research Procedure

Eligibility Criteria

In the process of searching for data through the Google Scholar, ScienceDirect, Wiley, ERIC, ProQuest, Fronteins and Web of Science databases, the research must meet several inclusion criteria, namely 1) the research is published in the 2022-20252 range, 2) the research is published in a journal indexed by SINTA, Scopun or Web of Science, 3) The research must use experimental classes of Ethno-Physics-based problem-based learning models and other classes of conventional learning models, 4) All studies must have complete data to calculate the effect size value dan 5) Student Research Sample SD, SMP dan SMA. From the data search, 25 studies were obtained that met the inclusion criteria published in 2022-2024 which can be seen in Table 2.

Data Collection

To obtain valid research data related to the influence of ethnobotanically charged project-based learning-STEM models on students' critical thinking skills in Science Learningcollected from Google Scholar, Mendeley, ScienceDirect, ERIC and ProQues. The keywords for data search are " Project Based Learning"; "STEM"; "Ethnobotany"; The Influence of the PjBL-STEM Model on Students' 21st Century Thinking Skills"; "PjBL-STEM is ethnobotically charged on 21st century thinking ability in science learning".

Statistical Analysis

Data analysis in this study calculates the effect size value of each study analyzed. The effect size value in this study is to calculate the effect of the influence of ethnobotanically charged project-based learning-STEM models on students' critical thinking skills in biology learning. According to (Borenstein et al., 2007) The stages of data analysis in the meta-analysis can be seen in (Figure 1.). Furthermore, the criteria for the effect size value in the study can be seen in Table 1.

Table 1. Category Effect Size Value

Effect Size	Category
0.0≤ES≤ 0.2	Low
0.2≤ES≤ 0.8	Medium
ES≥ 0.8	High

Source: (Borenstein et al., 2007); Bachtiar et al., 2023); Tamur et al., 2020)

Result and Discussion

Hasil Based on the results of data search through the database, 25 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 2.

Table 2. Effect Size and Standard Error Every Research

Code Jurnal	Years	Effect Size	Countries	Standard Error
PR1	2023	1.91	Indonesia	0.30
PR2	2023	0.91	Indonesia	0.28
PR3	2025	2.05	Pakistan	0.31
PR4	2025	1.19	India	0.40
PR5	2023	1.06	India	0.27
PR6	2025	0.81	China	0.22
PR7	2023	0.64	Indonesia	0.18
PR8	2025	0.89	Indonesia	0.39
PR9	2023	0.74	Indonesia	0.14
PR10	2025	1.72	Nepal	0.30
PR11	2024	1.38	Nepal	0.36
PR12	2024	0.48	Nepal	0.10
PR13	2024	0.71	India	0.20
PR14	2022	0.34	China	0.17
PR15	2022	0.94	China	0.40
PR16	2023	1.80	Indonesia	0.35
PR17	2025	2.10	Indonesia	0.33
PR18	2024	1.09	Indonesia	0.30
PR19	2024	0.66	Indonesia	0.33
PR20	2024	0.96	China	0.41
PR21	2022	0.79	Bangladesh	0.27
PR22	2025	1.95	Indonesia	0.17
PR23	2023	2.25	Indonesia	0.52
PR24	2024	0.68	Indonesia	0.20
PR25	2022	1.30	Australia	0.44

Based on Table 2, the effect size value of the 25 studies ranged from 0.39 to 2.25. According to (Borenstein et al., 2007) Of the 25 effect sizes, 8 studies had medium criteria effect sizes and 19 studies had high criteria effect size values. Furthermore, 25 studies were analyzed to determine an estimation model to calculate the mean effect size. The analysis of the fixed and random effect model estimation models can be seen in Table 3-4.

Table 3. Fixed and Random effect

	Q	df	p
Omnibus test of Coefficients Model	97.813	1	< 0.001
Test of Residual Heterogeneity	135.803	24	< 0.001

Table 4. Residual Heterogeneity Estimates

		95% Confidence Interval	
	Estimates	Lower	Upper
τ^2	0.240	0.113	0.520
τ	0.490	0.335	0.721
I^2 (%)	81.237	67.026	90.376
H^2	5.330	3.033	10.391

Based on Table 3 -4 , a Q value of 135.803 was obtained higher than the value of 97.813 with a coefficient interval of 95% and a p value of 0.001 < and I^2 (%) as 81.237; lower 67.026 dan upper 90.376. The findings can be concluded that the value of 25 effect sizes analyzed is heterogeneously distributed. Therefore, the model used to calculate the mean effect size is a random effect model. Furthermore, checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Tamur et al., 2020; Badawi et al., 2023; Ichsan et al., 2023b; Borenstein et al., 2007; (Pateda et al., 2024). The results of checking publication bias with funnel plot can be seen in Figure 2.

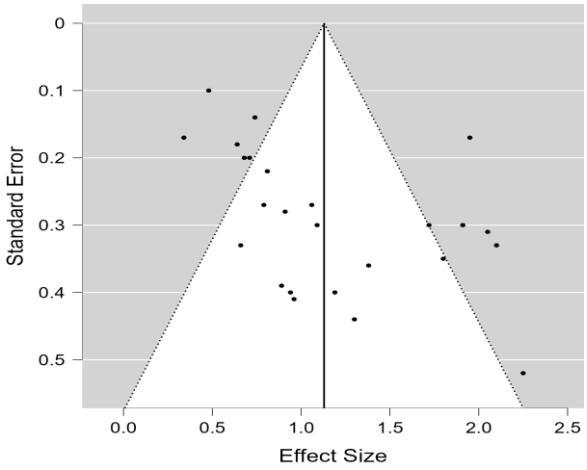

Figure 2. Funnel Plot

Based on Figure 2, the analysis of the funnel plot is not yet known whether it is symmetrical or asymmetrical, so it is necessary to conduct a Rosenthal Fail Safe N (FSN) test.

The results of the Rosenthal Fail Safe N calculation can be seen in Table 4.

Tabel 5. Fail Safe N

File Drawer Analysis			
	Fail Safe N	Target Significance	Observed Significance
Rosenthal	4032	0.050	< 0.001

Based on Table 4, the Fail Safe N value of 4032 is greater than the value of 5k + 10 = 5(25) + 10 = 135, so it can be concluded that the analysis of 25 effect sizes in this data is not biased by publication and can be scientifically accounted for. Next, calculate the p-value to test the hypothesis through the random effect model. The results of the summary effect model analysis with the random effect model can be seen in Table 5.

Tabel 6. Summary/ Mean Effect Size

Coefficient						
	Effect Size	Standard Error	z	p	95% Coefficient Interval	
					Lower	Upper
Intercept	1.129	0.114	9.890	< 0.001	0.906	1.353

Table 6, the summary effect size value is 1.129, standard error is 0.114 with 95% confidence interval lower 0.906 and upper 1.353. This finding shows that the project-based learning-STEM model with ethnobotany content has a significant effect on students' 21st century thinking skills in Science Learningcompared to the conventional model with a z value = 9.890 and p < 0.001 in the strong effect size category. The ethnobotanically loaded Project-Based Learning (PjBL)-STEM model offers an innovative approach to Science Learningby integrating ethnobotany concepts, project-based approaches, and STEM (Science, Technology, Engineering, and Mathematics) aspects (Zulkifli et al., 2022). This model allows students to explore the use of local plants in daily life through a project-based scientific approach. Thus, students not only understand biological concepts theoretically but also develop 21st-century thinking skills, such as critical thinking, problem-solving, communication, and collaboration in project completion based on real research (Pitorini et al., 2024).

The application of ethnobotanically charged PjBL-STEM in Science Learninghas been proven to improve students' critical thinking skills (Twaddle & Smith, n.d.). This is because this model requires students to analyze information in depth, evaluate various sources of literature, and relate biological concepts to real applications in people's lives(Anggrella & Sudrajat, 2024). For example, when students conduct research on the potential of medicinal plants in the surrounding environment, they need to understand the physiological mechanisms of the plant, conduct simple chemical analysis, and evaluate its benefits based on scientific studies. This kind of activity fosters systematic thinking skills and instills a scientific attitude in the learning process.

In addition, this model also contributes to strengthening students' collaboration and communication skills (Sudarmin et al., 2019). Project-based learning requires students to work in groups, divide tasks according to their respective competencies, and discuss their findings in academic forums. Effective communication is the key to success in this project, both in conveying ideas to teammates and in presenting research results to a wider audience. Therefore, the application of the PjBL-STEM Ethnobotanical model is in line with the needs of today's (Jones, 2024; Oktay et al., 2023)world of work, where interpersonal skills and teamwork are important aspects in various fields of the profession.

Furthermore, this learning model also facilitates the development of more complex problem-solving skills. Students are faced with

real challenges in identifying, processing, and interpreting data related to biodiversity and its potential in human life(Nihlah et al., 2024). Through a project-based learning cycle, they learn how to design solutions to environmental and health problems based on ethnobotanical research. This process encourages students to be more innovative and adaptive in overcoming problems, which is an essential competency in facing global challenges in the era of the Industrial Revolution 4.0 and 5.0 (Ulum, 2022; Yusuf, 2023).

Thus, the ethnobotanically charged PjBL-STEM model not only enriches students' understanding of biological concepts, but also significantly improves their 21st-century thinking skills (Rattanakha & Chatwattana, 2023). This model creates a more meaningful learning experience by connecting science with local culture and its application in real life(Rahmawati et al., 2024). Therefore, this approach is feasible to continue to be developed and implemented in Science Learningto prepare the young generation who are competitive, think critically, and are able to innovate in facing the dynamics of science and technology development (Ernawati et al., 2022; Sudarmin et al., 2023).

Conclusion

From the results of this study it can be concluded that the summary effect size value (d = 1.129; p < 0.005; Z = 9.890). This finding explains that there is an effect of project-based learning-STEM model with ethnobotanical content on students' 21st century skills in Science Learningcompared to the conventional model with strong effect size category. The application of this model in Science Learningproved to be effective in improving students' 21st century thinking skills, which include critical thinking, creative, collaborative, and problem solving. The integration of ethnobotanical concepts in project-based learning allows students to connect biological science with local culture, thus creating a more contextualised and meaningful learning experience. In addition, this model also encourages students to conduct scientific exploration, data analysis, and scientific communication in completing research-based projects, which are in line with the skill demands in the era of Industrial Revolution 4.0 and 5.0. Therefore, Ethnobotanical PjBL-STEM is recommended as an innovative learning strategy in biology education to equip students with the necessary skills to face future global challenges.

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