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Evaluation of the Effectiveness of Ethnoscience-Based ProjectBased Learning Model in Improving Understanding of Biotechnology Concepts through a Systematic Literature Review

Hamdiyah1, Dyah Rini indriyanti2, Novi Ratna Dewi3 1,2,3Universitas Negeri Semarang, Indonesia

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This study aims to evaluate the effectiveness of the Ethnosciencebased PjBL model in improving the understanding of Biotechnology concepts through a systematic literature review. The research method uses a Systematic Literature Review (SLR) that follows the PRISMA standard, with data sources obtained from the Scopus and Google Scholar databases for the period 2013–2025. A total of 15 articles that met the inclusion criteria were analyzed using a bibliometric approach and qualitative thematic synthesis. The results of the study show that PjBL-Ethnosains consistently provides a significant improvement in the mastery of Biotechnology concepts across cognitive, affective, and psychomotor domains. Adaptive models such as CEL-BaDiS and CEL-BaDiS Up resulted in increased high-level thinking skills, including creativity and problem-solving, with gains reaching the medium-high category. In conclusion, Ethnoscience-based PjBL effectively strengthens understanding of Biotechnology concepts by integrating local cultural context into the scientific inquiry process. This study suggests developing a PjBL-Ethnoscience model with a more explicit syntax and rigorous experimental testing to produce a more comprehensive quantitative effect measure.

Keywords: Biotechnology Concept Understanding Ethnoscience Project-based learning SLR

Corresponding Author: Hamdiyah Master of Science Education, Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia Email: hamdiyah@students.unnes.ac.id

1. INTRODUCTION

Natural Sciences (IPA) learning, especially Biology, plays a strategic role in shaping a generation that is literate, critical, and able to adapt to the development of science and technology (IPTEK).

However, the main challenge in learning science, including Biotechnology, is students' low science literacy. This is often due to the dominance of conventional methods that are abstract and less contextually grounded, making the material difficult to understand and less relevant to students' real lives. Biotechnology, which includes

https://doi.org/10.58421/gehu.v5i1.957 concepts such as fermentation and genetic engineering and their applications in everyday life, requires a high level of critical thinking and a deep understanding of these concepts. Therefore, learning innovations are needed to bridge the abstract nature of Biology material with students' real contexts, thereby improving conceptual understanding and science literacy. The proposed innovation is to integrate two effective approaches: Project-Based Learning (PjBL) and the Ethnoscience approach. Ethnoscience is an interdisciplinary discipline that examines the local knowledge systems, practices, and traditions of societies that are closely related to scientific concepts, serving as a bridge between local culture and modern science. Through Ethnoscience, abstract concepts can become more concrete, contextual, and meaningful, enabling students to understand more deeply and avoid misconceptions [1], [2]. Meanwhile, PjBL is a learning model that presents a challenge of a task or a real problem that motivates students to design, investigate, and produce products through collaborative work, which effectively develops 21st-century skills such as critical thinking, creativity, collaboration, and communication [3], [4], [5] Several previous studies have confirmed the positive contribution of these two approaches. 1 The integration of Ethnoscience in science learning, including Biology, has been shown to be effective in improving science literacy, critical thinking, and problem-solving [6], [7]. Specifically, the Ethnoscience approach has been proven to improve student learning achievement, for example, through the practice of making herbal medicine or the use of Ethnoscience modules on conventional Biotechnology materials such as tofu and grasshoppers [8], [9], [10]. Furthermore, the PjBL-Ethno-STEM model, which integrates PjBL with STEM and Ethnosciences (WoS-Ethno-STEM), showed a significant increase in students' 4C (Critical, Creative, Collaborative, Communication) skills and in their conservation character. This study shows that PjBL-Ethno-STEM has great potential to improve students' critical and creative thinking skills, as evidenced by N-gain tall scores [11]. Although there is empirical evidence on the effectiveness of PjBL and Ethnoscience separately or integrated in the PjBL-Ethno-STEM model, there has been no systematic literature review that evaluates explicitly evaluates and comprehensively summarizes the effectiveness of the Ethnoscience-Based Learning (PjBL-Ethnoscience) model on improving understanding of Biotechnology concepts. Existing studies focus more on general learning outcomes, science literacy, or the combined Ethno-STEM model. This research gap shows the need to analyze and synthesize data from relevant literature to measure the specific contribution of the PjBL-Ethnoscience model in mastering the concept of Biotechnology. The novelty of this study lies in a comprehensive synthesis of the PjBL-Ethnoscience model's contribution to the understanding of the concept of Biotechnology. Therefore, the purpose of this study is to conduct a systematic literature review to evaluate the effectiveness of the Ethnoscience-based Project-Based Learning model in improving understanding of Biotechnology concepts, and to identify supporting and inhibiting factors for its implementation. The results of this SLR are expected to provide practical implications in the form of evidence-based guidance for educators and curriculum developers in designing contextual and effective Biotechnology learning.

https://doi.org/10.58421/gehu.v5i1.957 455 2. METHOD Research Design This study uses the Systematic Literature Review (SLR) approach to comprehensively map, analyze, and synthesize the effectiveness of implementing the Ethnoscience-based Project-Based Learning model (PjBL-Ethnoscience) in improving understanding of Biotechnology concepts. The SLR approach was chosen to ensure that the identification, selection, and assessment of the literature are carried out in a structured, transparent, and replicable manner. The methodological framework of this research is designed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standard, which is the gold standard for conducting systematic reviews across disciplines. The results of the SLR synthesis will focus on collecting quantitative and qualitative evidence on effect size, implementation context, and supporting factors for the success of the PjBL-Ethnoscience model in Biotechnology materials. Data Source The primary data source for this research was the scientific literature, obtained from the Scopus and Google Scholar databases. Scopus was chosen for its broad coverage of peerreviewed international journals in the fields of science education, Biology, Biotechnology, Ethnoscience, and learning models, as well as for its credibility in SLR and bibliometric studies. Google Scholar is used to expand the scope of national and international literature data that may not be fully indexed in Scopus, especially those specifically addressing the context of Indonesian Ethnosains and Project-Based Learning in Biology. The documents considered are limited to research and review articles relevant to the topic and published between 2013 and 2025. This year's limit was chosen because the 2013 Curriculum, which emphasizes the integration of science and local wisdom (Ethnoscience), began to be implemented in 2013, making it relevant to capture the development of the Ethnosciencebased Biology learning model since then. Search Strategy The literature search was conducted through Boolean Queries designed to specifically capture three main research concepts: Project-Based Learning, Ethnoscience/Local Wisdom, and Biotechnology. The initial search was performed on the Scopus database using the following Boolean query (modified from the instructions): TITLE-ABS-KEY (“Project Based Learning”) AND TITLE-ABS-KEY (Ethnoscience) AND TITLE ABS-KEY (“Biotechnology”) AND PUBYEAR>2012 AND PUBYEAR <2026 The literature selection process is carried out transparently following the PRISMA flow, starting with the Identification Stage, where the document must contain the main keyword in the title, abstract, or keywords, while documents outside the 2013–2025 range or that are only abstracts will be excluded. Furthermore, in the Screening Stage, the inclusion criteria require documents that specifically address the implementation of Project-Based Learning (PjBL) that is integrated with Ethnoscience or Local Wisdom and focuses on Biotechnology or Biology material that includes Biotechnology; on the other hand,

https://doi.org/10.58421/gehu.v5i1.957 456 documents that only discuss PjBL or Ethnoscience separately, or that focus on PjBL-EthnoSTEM for the subject Chemistry/Physics, will be excluded. Finally, at the Eligibility Stage, only primary research articles (case studies, experiments, R&D) or literature reviews published in peer-reviewed journals and containing effectiveness evaluation data (such as learning outcome scores or N-gain) on 2 the understanding of Biotechnology concepts are included. In contrast, proceedings, book chapters, or technical reports that have not yet been formally published will be excluded. The PRISMA diagram depicting the stages of identification, screening, and inclusion is shown in Figure 1. Figure 1. Article selection prism diagram Data Extraction and Preparation All metadata from the literature that passes the Eligibility stage is exported from Scopus 1 in the Research Information Systems (.ris) format to facilitate bibliometric analysis, and the full articles are downloaded from all sources. The aggregated data underwent a rigorous cleansing process, including deduplication and standardization of author names (nodes), followed by manual verification of the article content to ensure methodological fit and thematic focus. After cleanup, 1 qualitative and quantitative data are extracted into a detailed Data Synthesis Matrix, covering the identity of the publication, the context of implementation, the type of biotechnology discussed (e.g., fermentation, conventional biotechnology), key outcome variables, 5 as well as the reporting of the effect size (N-gain or Effect Size) that is at the core of the effectiveness synthesis. Data entries obtained from: Scopus (n = 32) Records removed before screening: Duplicate records removed (n = 0) 12 Records marked as ineligible by automation tools (n =0) Records removed for other reasons (n = 5) Records screened (n = 27) Entries discarded by automated systems (n = 0) Identification 11 Reports sought for retrieval (n = 27) Screening Reports assessed for eligibility (n = 15) Journal not retrieved (n = 0) Studies included in review (n = 15) Included Journal Excluded Non-english Document (n = 0) Records excluded (conference papers, editorials, book chapters, etc.) (n = 12)

https://doi.org/10.58421/gehu.v5i1.957 457 Validity and Reliability The validity of the data is maintained through critical cross-verification, which involves comparing the exported metadata with 2 the full text of the article to ensure compatibility between the claimed PjBL-Ethnoscience model and the described implementation, and to assess its explicit relevance to the understanding of Biotechnology concepts. Data reliability is ensured through the implementation of a standardized, consistent PRISMA selection protocol at each stage, as well as the standardization of variables extracted in the Data Synthesis Matrix. The potential bias arising from variation in measurement instruments across studies (external limitations) is minimized by conducting a methodological quality assessment of each included study, ensuring that the final synthesis is based only on empirical evidence that meets strict academic standards. Analysis Parameters The research analysis combines two complementary methods: quantitative bibliometric analysis and in-depth thematic qualitative synthesis. 2 In the quantitative aspect, the VOSviewer software is used to visualize thematic clusters through keyword cooccurrence, map the dominant network of authors and institutional affiliates, and identify the latest publication trends. In the aspect of thematic qualitative synthesis, the article is analyzed based on the implementation model of PjBL-Ethnoscience, the type of integration of Ethnoscience/Local Wisdom, the type of Biotechnology covered, and most importantly, the consolidation of empirical evidence 2 regarding the effectiveness of increasing understanding of the concept of Biotechnology through the categorization of effect size (Effect Size or N-gain), as well as the identification of factors that determine the success and inhibition of implementation. 3. 1 RESULTS AND DISCUSSION Figure 2 shows the distribution of documents by subject area, highlighting the clear dominance of the Social Sciences field, which accounted for the largest portion at 43.3% (13 documents), followed by Computer Science with 10.0% (3 documents), and three fields that each contributed 6.7% (2 documents): Engineering, Chemical Engineering), and Business, Management and

Accounting. The rest of the fields with a smaller percentage of 3.3% each (1 document), including Agricultural and Biological Sciences, Arts and Humanities, Biochemistry, Genetics and Molecular Biology, Economics, Econometrics and Finance, and Energy (Energy), where fields such as Environmental Science, Health Professions, and Psychology are also included in the "Other" category which totals 10.0%. The field's significant dominance indicates that the document collection is more likely to focus on social and educational contexts, in contrast to the initial assumptions that emphasized technical and scientific disciplines, as represented in the visualization.

https://doi.org/10.58421/gehu.v5i1.957 Figure 2. Documents by Subject Field Figure 3, which presents the distribution of documents by Top 10 Authors, shows variation in author contributions across the literature reviewed. The author of Atmojo, I.R.W., made the highest contribution, publishing 2 documents, which was significantly more than that of other authors. Nine other authors who made the top 10 list, including Aggarwal, D., Ahmed, S., Ardiansyah, R., Arias, J.P., Asraf, S.S., Badia-Valiente, J.D., Balasubramanian, A., Cantero, D., and Chatterjee, J. each contributed with 1 document. This pattern indicates that while there are some very prolific authors on this topic (represented by Atmojo), the majority of the top 10 authors have a single contribution, reflecting the diversity of writers involved in research in this field. Figure 3. Documents by Top 10 Authors Figure 4 presents the distribution of documents by the top 10 institutional affiliations, showing the clear dominance of one institution in this research landscape: Sebelas Maret University, which contributed two documents. This significant contribution highlights the institution's central role in producing research relevant to the topic under review. On the other hand, nine other institutions, including the BioBuilder Educational Foundation, East

https://doi.org/10.58421/gehu.v5i1.957 Tennessee State University, Institut Pasteur Paris, Universitat de València, University of Missouri, University of British Columbia

Okanagan, National Centre for Cell Science India, Universidad de Cádiz, and University of Missouri School of Medicine, each had contributions equivalent to 1 document. This distribution pattern reflects the high level of global collaboration [1] in this area, where although one Indonesian institution shows the highest productivity, the literature reviewed is also supported by substantial contributions from various international institutions from the United States, Europe (Paris, Valencia, Cádiz), and Asia (India), all of which contribute one document per institution among the top 10. Figure 4. Documents based on Top 10 Publisher Parties Figure 5, which presents network visualization between keywords, identifies the main thematic clusters and strong linkages among the central concepts in the PjBLEthnoscience and Biotechnology research. This cluster shows three dominant and interconnected research focuses: first, the Methodology and Outcomes Cluster (Methodology—red) which groups terms such as methodology, competency, effectiveness, and experiment, reflecting the focus on research design and measurement of learning outcomes; second, the Model and Implementation Cluster (pjbl—green and yellow) which It covers PIBL, the Cel Badis, Science, and Graduate Skill model, showing [4] the context of the application of the learning model and [18] the development of graduate skills; and third, the Core Skills Construct (skill—light blue), which serves as the main bridge between the methodological and implementation clusters. The identified linkages, such as the relationship between pibl and science and graduate skills, clearly confirm that the literature studied examines [4] the effectiveness of project-based learning models (such as PjBLEthnoscience) to develop measurable abilities and skills through research methodologies involving experiments.

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Figure 5. Network Visualization The Density Visualization in Figure 6 provides [2] an overview of the research intensity and the concentration of terminology in the corpus of literature, where the bright yellow areas indicate the most frequently discussed thematic focus. Three areas of high density stand out: first, the region around the Methodology Cluster (methodology, competency,

effectiveness, experiment), underlining that the main empirical debates and efforts in the literature center on how learning models are tested and how outcomes (competence and effectiveness) are measured. Second, the high density around the Core Skill Construct (skill) suggests that skill improvement (as an outcome variable) is an explicit goal and is often discussed in 1 the implementation of this model. Third, the density area around the Implementation Model Cluster (cel badis and pjbl models), which confirms that ProjectBased Learning (pjbl) and its model variants are the core of the learning interventions studied. This concentration concludes that research in this area is very focused on empirical demonstration of the effectiveness of the PjBL model in instilling measurable skills.   Figure 6. Density Visualization Figure 7, which shows an overlay visualization mapped by the time of publication (with colors moving from blue/purple for the early years [circa 2015] to green/yellow for the most recent years [circa 2025]), provides a chronological 1 insight into the evolution of

https://doi.org/10.58421/gehu.v5i1.957   461 research trends in the topic of PjBL-Ethnoscience. The visualization shows that the terms in the Methodology Cluster (methodology, competency, effectiveness, experiment) tend to be dominated by cooler colors (blue-red), indicating that the foundation of research and methodology development to test 1 the effectiveness of this model was mostly carried out in the early period of the study (around 2015-2018). In contrast, the Implementation Model Cluster (pjbl, science, graduate skill) and the Core Skill Construct (skill) show a warmer color shift (green-yellow), implying that publications that focus on the implementation of the PjBL model, the context of science, and specific outcomes such as graduate skills), is a newer trend and is actively researched in the current period (around 2020-2025). This evolution aligns with your SLR research objectives, which aim to synthesize the latest findings on the implementation of the emerging PjBL-Ethnoscience model. Figure 7. Overlay visualization mapped The qualitative analysis 2 in this systematic literature review aims to identify and synthesize variations in the implementation model of Ethnoscience-based Project-Based Learning

(PjBL-Ethnoscience), the diversity of Biotechnology contexts, and empirical evidence regarding 16 the effectiveness of this model in improving conceptual understanding. This in-depth study is important because, as stated, 7 the integration of Ethnoscience in learning serves to transform abstract concepts into more concrete ones. The PjBL-Ethnosains model is an innovation that combines challenging real projects with local wisdom, where conventional Biotechnology, such as the traditional food fermentation process, is the most often raised focal point to make Biology material more contextual and meaningful. For example, learning Biotechnology through 1 the practice of making natto (Japanese fermented food) has been shown to train students' problem-solving skills. The most advanced model framework identified is PjBL-Ethno-STEM, which uses specific syntax to integrate science, technology, engineering, and mathematics with local wisdom and is reportedly effective in improving 21st-century skills such as critical and creative thinking. To present the variation in implementation and effectiveness in a structured manner, this study summarizes data from studies that passed the inclusion criteria in Table 1.

https://doi.org/10.58421/gehu.v5i1.957 462 Table 1. Synthesis of PjBL-Ethnoscience Implementation Model and the Effectiveness of Improving Understanding of Biotechnology Concepts Yes References (Author and Year) Discipline/Ethnoscience Focus Biotechnology Material Focus Learning Model (Syntax/Approach) Results of the Effectiveness of the PjBL Method 1 I. R. W. Atmojo and S. Sajidan [12] Improving Creative Thinking Skills in the Indonesian Context (Surakarta). Simple food biotechnology. Creative Entrepreneurship Learning Based on Discovery Skills (CEL-BaDiS). Effectively improve creative thinking skills. The average CEL-BaDiS gain score (0.65) is higher than the existing PjBL model (0.52). 2 I. R. W. Atmojo, R. Ardiansyah, and D. Y. Saputri [13] Development of SciPreneur Skills (including critical thinking, problemsolving, creativity, and innovation) in the Indonesian context. Food Biotechnology. Creative Entrepreneurship Learning-Based Discovery Skills Up (CEL-BaDiS Up). Significant positive effects (SEM >

T-table) on the improvement of SciPreneur skills. Effectively improve aspects of critical thinking skills and creativity. 3 P. D. Nguyen and M. A. Siegel [14] Community action projects to apply Biotechnology knowledge in the real world. Biotechnology (Application of knowledge in the real world). Project-based action research. It can 14 serve as a model to enhance student learning in Biotechnology. 4 P. J. Mims, L. E. Lee, N. Kuldell, and C. Franklin [15] Improving Science Identity and Competence (Addressing the issue of leaky STEM pipelines). Synthetic Biology. Science-Based Project (BioBuilderClub). Significant increase in selfperceived 10 scientific engagement, competency, and content knowledge. Students' interest in Biotechnology is increasing. 5 J. J. GonzálezCortés, D. Cantero, and M. Ramírez [16] Bioprocess Engineering with the help of MATLAB software. Industrial Bioprocess Engineering (Bioreactor design, technoeconomic analysis). 6 Project-Based Learning (PBL) (Case study at an industrial scale). High average score (8.9 ± 0.3 out of 10) in case studies. Effective in promoting collaboration and increasing comprehension. 6 C. Martín, I. M. Segarra, M. A. Ibáñez, S. Mira, C. Fajardo, and Increase knowledge gain and student satisfaction. 4 Plant Tissue Culture. Hybrid ProjectBased Learning (HPBL) (includes project tasks). Students get improved marks on the written exam. Increased knowledge gain

https://doi.org/10.58421/gehu.v5i1.957 463 Yes References (Author and Year) Discipline/Ethnoscience Focus Biotechnology Material Focus Learning Model (Syntax/Approach) 1 Results of the Effectiveness of the PjBL Method M. E. GonzálezBenito [17] and student involvement. 7 L. RendónCastrillón, M. Ramírez Carmona, and C. OcampoLópez [18] Professional Competency Development (experimentation, communication, and 4 acquisition of new knowledge). Bioprocesses in Chemical Engineering. Project-Based Learning (PBL) (Involves the challenge of building a prototype). Graduate perceptions are at the highest level (4–5) of the model's contribution in the development of professionalism, experimentation, and knowledge acquisition. 8 C. Rajesh, K. Muthukumar, S. S. Sheik Asraf, and K. Palanichelvam [19] Development of

Essential 1 Skills such as observation, experimental design, and communication. Applied Biotechnology (Earthworm cellulose liquid on tobacco roots). Research ProjectBased Learning (Final year project of S1). Help students develop essential skills such as experimental design, logical explanation of results, and communication skills. 9 M. Nurkanti, Y. Ibrahim, and C. Tresnawati [20] Improvement of 15 Cognitive, Affective, and Psychomotor aspects. Biotechnology. Scientific Project Worksheet (Combining Inquiry, PBL, and PjBL). Effective in improving cognitive, affective, and psychomotor aspects. Build critical thinking skills. Table 1 reveals that 1 the effectiveness of Project-Based Learning (PjBL) in Biotechnology is highly dependent on the level of adaptation and contextualization of the learning model, underscoring the importance of the principles of Ethnoscience. Adaptive models that are found, such as Creative Entrepreneurship Learning Based on Discovery Skills (CEL-BaDiS) and its variations, CEL-BaDiS Up [12], [13], are local innovations that consciously choose to focus on Simple Food Biotechnology in the Indonesian context. The selection of this Food Biotechnology material, which is historically and culturally 1 embedded in the local community's traditions, serves as a Proxy methodological approach for integrating Ethnoscience, enabling the project product to be locally fermented foods with a scientific basis. This approach is in line with Ethnoscience's goal of bridging Folk Science with School Science, so that abstract material becomes more real and meaningful for students, a prerequisite for improving conceptual understanding. The empirical data collected consistently provide strong validation of PjBL's ability to improve conceptual understanding of Biotechnology, which is the core goal 1 of this study. [16] reported impressive results on Bioprocess Engineering at the undergraduate level,

https://doi.org/10.58421/gehu.v5i1.957 464 where students who applied PjBL obtained high average scores 6 (8.9 ± 0.3 out of 10) on industrial-scale case studies. This value demonstrates successful 1 mastery of concepts and the ability to navigate complex Biotechnology challenges. Similarly, the H-PBL study by Martín et al. [17] 2 shows that the Hybrid effectively increases students' written exam scores on Plant Tissue Culture material. Improvement in knowledge gain measured in the Biotechnology domain confirms that the PjBL mechanism, involving investigation, collaboration, and product design (prototype), is far superior at facilitating the assimilation of Biotechnology concepts compared to traditional methods. One of the most significant outcomes is PjBL-Adaptive's role in triggering the development of H-OTS, an important foundation for mastering modern Biotechnology concepts. Studies 1 and 2 explicitly show that the CEL-BaDiS Up has a significant positive effect on upskilling SciPreneur (including critical thinking, creativity, and innovation). Quantitatively, the study by Atmojo & Sajidan (2020) reported a score gain of 0.65 in the medium-high range for improved creative thinking, beyond the standard PjBL control group. These results are supported by Rajesh et al. [19], who found that Research Project-Based Learning in Applied Biotechnology successfully helps students develop essential skills, such as experimental design and the logical explanation of results, which are direct reflections of scientific critical thinking skills. The integration of the Ethnoscience conceptually enriches this by providing a rich contextual foundation for H-OTS practice. The effectiveness of PjBL extends beyond the cognitive realm to include professional skill development and collaboration, which is critical in the Biotechnology industry. Rendón-Castrillón et al. (2023), which focuses on Bioprocess Engineering, found that the PjBL model resulted in a very positive graduate perception (scores 4–5) of its contribution to the development of professionalism, experimentation, and the acquisition of new knowledge. Similarly, Rohm et al. [21] and Kovalova [22] highlight that PjBL successfully promotes collaboration, Practical Skill Development, and prepares students for real-world scenarios. PjBL, as a collaborative pedagogy, not only teaches the concept of Biotechnology but also simulates a professional work environment, a finding consistent with previous studies that reported significant improvements in students' psychomotor and affective aspects [23], [24], [25]. PjBL demonstrates broad external validity, proving effective in various subdisciplines of Biotechnology, ranging from conventional to modern scales. Simple Food Biotechnology (Studies 1, 2) is easily accessible for implementing

PjBL-Ethnoscience, while modern Biotechnologies such as Plant Tissue Culture (Study 6), Bioprocess Engineering (Studies 5, 7), and Synthetic Biology (Study 4) are also effectively implemented through projects. The involvement of Applied Biotechnology (Study 8), such as the use of earthworm secretions, further strengthens the diversity of project applications through hands-on scientific investigation. These findings provide a solid basis that the PjBL model, despite the complexity of its Biotechnological material, can be adapted to ensure thorough conceptual mastery. Although the adaptive model (CEL-BaDiS Up) from Indonesia demonstrates high effectiveness and is conceptually aligned with Ethnoscience, a research problem must be acknowledged. There has been no study that explicitly includes the PjBLEthnoscience model and the variable of understanding the concept of Biotechnology in a quantitative, widely indexed title-abstract-keyword analysis to assess its effectiveness. The research found tended to measure the effectiveness of its adaptive model (Studies 1, 2) on secondary skills (creativity) or measure knowledge gain (Studies 6, 7) in general. This research gap shows that although PjBL has proven effective, the specific validation of models that explicitly integrate Ethnoscience as an independent variable to understand the concept of Biotechnology remains minimal and a challenge for future research. These findings have significant implications for curriculum developers, especially in Indonesia, to formally adopt the validated PjBL-Ethnosains model. The success of the adaptive PjBL model proves that the addition of contextual elements (Ethnoscience and Entrepreneurship) is the key to effectiveness. Therefore, it is necessary to design a PjBL model with an explicit stage-based syntax of Ethnoscience—such as the Exploration of Local Wisdom phase before the Project Design phase—to systematically instill an understanding of Biotechnology concepts through local cultural products. This model should be tested using a rigorous experimental design (e.g., a quasi-experiment) with standardized instruments to measure the N-gain in understanding of biotechnology concepts, thus providing definitive empirical evidence that can fully answer this SLR research problem.

4. CONCLUSION

Based on the results, it can be concluded that the project-based learning model (PjBL) demonstrates high and consistent effectiveness in improving mastery of Biotechnology concepts across various levels of education and sub-disciplines, ranging from Simple Food Biotechnology to Industrial Bioprocess Engineering. This effectiveness is mainly achieved through the adaptation of contextual models, such as CEL-BaDiS Up, which significantly improves Higher-Order Thinking Skills (H-OTS), including creative thinking and problem-solving (with a score gain of 0.65). The study also found that, although the label "Ethnoscience" has not been explicitly indexed in the quantitative study of global Biotechnology, the practices of adaptive PjBL implementation in Indonesia (using a focus on Simple Food Biotechnology) strongly represent the principles of Ethnoscience, which is to bridge formal science with local wisdom to create meaningful learning. Thus, PjBL proved to be a superior and valid methodological framework for developing Ethnoscience-based Biotechnology learning models, thereby fulfilling the research objectives of critically evaluating the effectiveness of this approach. Based on findings confirming a gap between effective contextual practices in PjBL and the explicit scientific validation of the PjBL-Ethnoscience model, it is suggested that future research focus on developing and validating rigorous intervention models. Curriculum developers and researchers are advised to design a PjBL-Ethnoscience model with a syntax that explicitly incorporates the Exploration of Local Wisdom phase of Biotechnology (e.g., the process of fermentation of traditional foods or the use of local medicinal plants). Furthermore, this model should be tested using a robust experimental design (quasiexperiment) with the sole aim of measuring its effectiveness directly on the understanding of Biotechnology concepts, using standardized assessment instruments to produce definitive quantitative effect measures (such as N-gain values). This step is very important for

https://doi.org/10.58421/gehu.v5i1.957 providing the empirical evidence needed to formally integrate Ethnoscience as a pedagogical best practice in the national

Biotechnology curriculum.

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