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Enhancing 21st-Century Skills through Blended Problem-Based Learning with Ethnoscience Integration: A Mixed-Methods Study in Indonesian Junior High Schools

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Abstract. Integrating 21st-century skills into science education remains challenging in Indonesia, particularly in bridging modern pedagogical approaches with culturally relevant learning experiences. This study aimed to develop, implement, and evaluate a Blended Problem-Based Learning model incorporating ethnoscience for junior high school science education in Indonesia, focusing on its validity, practicality, and effectiveness in improving students' critical thinking, communication, and creativity skills. Using a mixed-methods research design, the study employed the Plomp's framework for model development. Participants included 120 eighth-grade students and 9 science teachers from three schools representing urban, suburban, and rural settings. Data collection involved expert validation, classroom observations, teacher interviews, student focus groups, and pre-post assessments of 21st-century skills. The model demonstrated high validity (M = 4.72/5.0) across content alignment, instructional design, cultural relevance, and technological accessibility. Practicality assessment showed strong feasibility (M = 4.65/5.0) in classroom implementation. Significant improvements were observed in critical thinking (ΔM = 16.35, d = 1.47), communication (ΔM = 15.05, d = 1.35), and creativity (ΔM = 16.50, d = 1.43). The integration of ethnoscience particularly enhanced student engagement and cultural appreciation while supporting academic achievement. This study provides empirical evidence for the effectiveness of culturally responsive Blended-Learning approaches in developing 21st-century skills and offers practical insights for educators and policymakers in implementing innovative pedagogical strategies within diverse educational contexts.

Keywords: Blended Problem-Based Learning; ethnoscience integration; 21st-century skills; cultural-responsive teaching; Merdeka Curriculum

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1. Introduction

The rapid advancement of information and communication technology (ICT) has fundamentally transformed education in the 21st century. Central to these developments are educational frameworks that emphasize critical thinking, collaboration, communication, and creativity—collectively known as 21st-century skills (Kereluik et al., 2013). These competencies are essential for equipping learners to navigate a world that is increasingly shaped by complex, global challenges. However, the effective integration of 21st-century pedagogical strategies into classroom practices remains a significant challenge, particularly in regions such as Indonesia where disparities in teacher preparedness and resource availability are pronounced (World Bank, 2022). These 21st-century skills encompass critical thinking, communication, collaboration, and creativity, which are essential for addressing complex, global challenges (Kereluik et al., 2013).

In Indonesia, the Merdeka Curriculum offers a promising framework for revitalizing education by promoting student-centered and flexible learning models (Amrullah et al., 2024; Ihsani, 2024; Nada & Alkhawa, 2024; Ningsih et al, 2024; Susanto, 2023). Yet persistent gaps in educational outcomes, as evidenced by low Programme for International Student Assessment (PISA) scores and limited mastery of critical skills among students, highlight the urgent need for innovative approaches (Organisation for Economic Cooperation and Development [OECD], 2021). Despite the emphasis on 21st-century skills in education, integrating them into science curricula remains a challenge in culturally diverse contexts such as Indonesia. Furthermore, the integration of ethnoscience—defined as the contextualization of scientific concepts within local cultural practices—has been identified as an underutilized strategy for making science education more relevant and engaging, particularly in culturally diverse settings (Anane, 2023; Yuliyanti et al., 2024; Yusof et al., 2024; Zidny et al., 2021). However, few studies have explored the potential of blending ethnoscience with contemporary pedagogical models such as Blended Problem-Based Learning (Blended-PBL), leaving a significant gap in the literature.

Anane (2023) and Zidny et al. (2021) highlight the lack of studies integrating ethnoscience into Blended Learning models to foster 21st-century skills. However, they fail to address how these models can be adapted for culturally diverse and resource-limited contexts, which this study seeks to explore.

Blended-PBL represents a confluence of two powerful educational paradigms: Blended Learning, which integrates face-to-face and online learning modalities for greater flexibility and accessibility (Hamsiah, 2023; Handayani et al., 2023; Hasanah et al., 2023; Nugraha et al., 2024; Supramono & Hidayati, 2023), and Problem-Based Learning (PBL), a constructivist approach that engages students in solving real-world problems (Barrows, 1986). Despite its proven effectiveness in fostering critical thinking and problem-solving skills (Fitria et al., 2024; Kusumawardani & Aminatun, 2024), the adoption of Blended-PBL in Indonesian schools has been hampered by challenges such as inadequate teacher training, limited digital infrastructure, and the lack of culturally contextualized instructional materials. These barriers underscore the need for a robust,

empirically validated model that combines Blended-PBL with ethnoscience to enhance both pedagogical efficacy and cultural relevance.

The present study addresses this gap by developing and evaluating a Blended-PBL model that incorporates ethnoscience for integrated science education in Indonesian junior high schools. The study aligns with the emphasis of the Merdeka Curriculum on 21st-century skills and culturally responsive teaching, contributing to global discussions on educational innovation. Specifically, this study seeks to answer the following research questions:

1. How valid is the developed Blended-PBL model with ethnoscience integration in terms of theoretical and practical considerations?
2. How practical is the implementation of the Blended-PBL model with ethnoscience integration in classroom settings?
3. How effective is the Blended-PBL model with ethnoscience integration in improving students' critical thinking, communication, and creativity skills as distinct competencies?

By addressing these questions, this research not only advances theoretical understanding but also provides actionable insights for educators and policymakers. Its findings have the potential to bridge the gap between global pedagogical trends and local educational contexts, thereby fostering more equitable and culturally relevant learning experiences.

2. Methodology

The methodology of this study was employed to ensure a systematic and rigorous approach to developing, implementing, and evaluating the Blended-PBL model with ethnoscience integration. The study adopted a research and development (R&D) framework that followed Plomp's development model (Plomp, 2013), which consists of three main phases: the Preliminary Research Phase, the Development or Prototyping Phase, and the Assessment Phase. This methodology enabled iterative refinement of the instructional model and provided robust evidence of its validity, practicality, and effectiveness.

2.1 Research Design

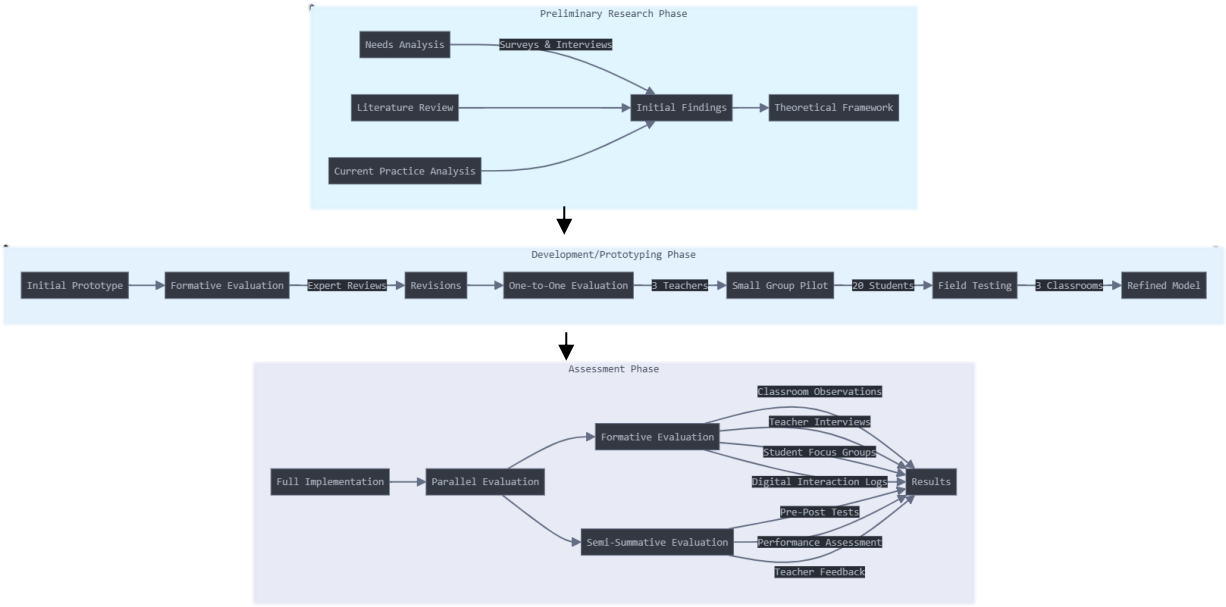

Figure 1: Preliminary, Development, and Assessment phases of the study (Adapted from Plomp, 2013)

Figure 1 shows that the study utilized a mixed-methods design, combining quantitative and qualitative approaches to provide a comprehensive understanding of the development and impact of the Blended-PBL model. The qualitative component focused on validating the theoretical framework and gathering insights from educators, while the quantitative component assessed the model's practicality and effectiveness through classroom implementation. This design aligned with Creswell and Plano Clark's (2017) recommendation for mixed methods to address complex educational interventions comprehensively.

2.2 Participants

The participants included junior high school science teachers and eighth-grade students from three schools in Indonesia representing urban, suburban, and rural settings. The schools were purposefully selected to ensure diversity in terms of resource availability and demographic composition, as recommended by Patton et al. (2015) for maximizing the generalizability of the findings. A total of 120 students (aged 13–14 years) and 9 science teachers participated in the study. The teachers were selected based on their willingness to implement the Blended-PBL model and their teaching experience in science subjects. Before the study, all teachers attended a two-day training workshop on Blended-PBL and ethnoscience to ensure uniform understanding and implementation.

Table 1: Demographic profile of participants

Variable	Category	*N* (%)
Students		120 (100)
Gender	Male	56 (46.7)
	Female	64 (53.3)
Location	Urban	40 (33.3)
	Suburban	40 (33.3)
	Rural	40 (33.3)
Teachers		9 (100)
Teaching Experience	1–5 years	3 (33.3)
	6–10 years	3 (33.3)
	>10 years	3 (33.3)

2.3 Development of the Blended-PBL Model

The development of the Blended-PBL model followed Plomp's three-phase model, beginning with the Preliminary Research Phase. During this initial phase, a comprehensive needs analysis was conducted through surveys and interviews with teachers and students and an extensive literature review that focused on the principles of Blended Learning (Hamsiah, 2023; Handayani et al., 2023; Hasanah et al., 2023; Nugraha et al., 2024; Supramono & Hidayati, 2023) and PBL strategies (Barrows, 1986). The research team analyzed current instructional practices, examined existing curriculum frameworks and cultural contexts, and documented technological infrastructure and resource availability. The findings notably highlighted a significant lack of culturally relevant instructional materials and limited opportunities for students to develop 21st-century skills.

The second phase, the Development or Prototyping Phase, involved designing the initial prototype based on the preliminary research findings. This phase was characterized by iterative cycles of formative evaluation, including expert reviews by education technology specialists and ethnoscience experts, one-to-one evaluation with three teachers, small group pilot testing with 20 students who had similar characteristics with the actual participants, and field testing in three classrooms. Throughout this phase, the model underwent continual refinement based on feedback from each evaluation cycle. The team developed comprehensive supporting materials, including lesson plans, multimedia resources, and assessment tools, while ensuring theoretical soundness and alignment with educational standards. Importantly, both online and offline versions of materials were created to accommodate varying resource availability across the different educational settings.

The final Assessment Phase involved implementing the refined model across all three participating schools. This phase encompassed both formative and semi-summative evaluation methods. The formative evaluation included classroom observations, teacher interviews, student focus groups, and analysis of digital interaction logs. Semi-summative evaluation was conducted through

pre- and post-tests of 21st-century skills, student performance assessments, and teacher feedback surveys. The research team meticulously analyzed the implementation challenges and successes while documenting the necessary adaptations for different school contexts. This comprehensive evaluation approach ensured the model's effectiveness and adaptability across various educational environments while maintaining alignment with the objectives of the Merdeka Curriculum.

2.4 Implementation

Implementation was conducted in three stages: pilot testing, field trials, and full implementation. Pilot testing involved a small group of 20 students to identify and rectify initial challenges. Field trials were conducted in three classrooms, each representing one of the selected schools. Teachers facilitated the lessons following the Blended-PBL model, with students engaging in both online and offline activities that were designed to foster critical thinking, creativity, and communication skills. Throughout the implementation, data were collected on teachers' and students' experiences through classroom observations, focus group discussions, and digital interaction logs. Regular debriefings with the teachers provided iterative feedback, allowing for continual improvement of the model.

2.5 Data Collection and Instruments

Quantitative data were collected using validated instruments, including a Critical Thinking Skills Test (CTST) adapted from Facione (2011), a Creativity Self-Assessment Scale (CSAS) of Giancola et al. (2024), and a communication rubric aligned with 21st-century skills frameworks (Kereluik et al., 2013). Pre- and post-tests were administered to measure changes in students' skills. The socioeconomic status of students and their prior exposure to similar learning models may have influenced the outcomes and were considered potential confounding variables. Qualitative data were gathered through semi-structured interviews with teachers and students and through open-ended survey questions. Classroom observations focused on students' engagement and the feasibility of the instructional strategies. Data from multiple sources were triangulated to enhance the reliability and validity of the findings (Creswell & Poth, 2016).

2.6 Data Analysis

Quantitative data were analyzed using descriptive and inferential statistics. Paired sample t-tests were conducted to determine the significance of differences between the pre- and the post-test scores, and effect sizes were calculated to assess the magnitude of changes. Qualitative data were analyzed thematically using NVivo software, following Braun and Clarke's (2006) six-step framework. Themes related to teachers' perceptions, student engagement, and cultural relevance were identified and cross-validated with the quantitative results.

2.7 Ethical Considerations

Ethical approval for the study was obtained from the institutional ethics review board. Participants provided informed consent, with parental consent obtained for student participants. Confidentiality and anonymity were maintained throughout the study, and participants were free to withdraw at any stage.

3. Results

3.1 Validity of the Blended-PBL Model with Ethnoscience Integration

The validity of the Blended-PBL model was assessed through expert evaluation using a comprehensive validation rubric covering four dimensions: content alignment, instructional design quality, cultural relevance, and technological accessibility. Quantitative results indicated consistently high scores across all dimensions, with an average validity score of 4.72 out of 5 (*SD* = 0.21), reflecting strong expert agreement on the model's educational and cultural robustness.

Table 2: Validity scores of the Blended-PBL model (Expert evaluation)

Dimension	Mean *(SD)*	Range
Content alignment	4.85 (0.15)	4.5–5.0
Instructional design quality	4.75 (0.18)	4.4–5.0
Cultural relevance	4.70 (0.22)	4.3–5.0
Technological accessibility	4.58 (0.29)	4.0–5.0
Overall	4.72 (0.21)	4.3–5.0

The high average scores reflect the model's strong alignment with the goals of the Merdeka Curriculum and its relevance in fostering 21st-century skills. Content alignment received the highest rating, indicating that the learning materials and activities effectively integrated science concepts with problem-solving and ethnoscience elements. However, the slightly lower scores in technological accessibility highlight concerns about equitable implementation, especially in rural settings where internet connectivity and digital resources may be limited.

To complement the quantitative findings, expert interviews provided rich qualitative data that offered nuanced perspectives on the model's strengths and areas for improvement. Experts unanimously praised the integration of ethnoscience, noting its potential to make science education more meaningful and culturally responsive.

Expert 1 stated, "This model bridges the gap between theoretical science and students' lived experiences. Using ethnoscience examples such as traditional weaving or herbal medicine is an excellent way to connect learning to real life." This highlights the relevance of the model in fostering deeper student engagement by making abstract concepts relatable.

Another expert remarked, "The instructional design is well-structured, particularly the clear problem-solving phases that align with Blended Learning and PBL principles. However, the digital tools should include offline options to accommodate rural students with limited internet access" (Expert 5). This aligns with the lower quantitative score in technological accessibility and reinforces the need for adaptable resources.

A third expert shared, "The content alignment is exceptional. The modules are well-sequenced and scaffold students' critical thinking effectively, but there is room for improvement in supporting teachers who are not yet familiar with

ethnoscience" (Expert 3). This feedback underscores the importance of professional development for teachers to maximize the model's impact.

Additional feedback pointed to the potential of the model to foster inclusivity. An expert explained, "Ethnoscience validates students' cultural heritage, which is particularly important in a multicultural context like Indonesia. It encourages pride in their identity while learning modern science" (Expert 1). This highlights the dual benefit of the model in promoting academic and cultural growth.

To address the slightly lower score in technological accessibility, one expert suggested, "The model should include printable worksheets and downloadable multimedia resources so students in remote areas can participate fully without relying on stable internet" (Expert 4).

The quantitative and qualitative data collectively confirm the validity of the Blended-PBL model with ethnoscience integration. High scores in content alignment and instructional design reflect the model's ability to achieve educational objectives effectively, while expert feedback highlights its innovative use of cultural elements to make learning relevant. However, the slightly lower scores and concerns regarding technological accessibility indicate the need for further refinement to ensure inclusivity in diverse educational settings. Overall, the findings support the model's strong foundation and potential for effective implementation, provided these challenges are addressed through iterative improvements.

3.2 Practicality of the Blended-PBL Model in Classroom Settings

The practicality of the Blended-PBL model was evaluated using a combination of classroom observations, teacher feedback, and a structured evaluation rubric. Quantitative results indicate a high overall practicality score of 4.65 out of 5 (SD = 0.19), demonstrating the model's feasibility and effectiveness in real-world classroom settings. Practicality was assessed across three key dimensions: ease of use for teachers, student engagement and participation, and feasibility within classroom time. Detailed results are shown in Table 3.

Table 3: Practicality scores of the Blended-PBL model (Teacher evaluation)

Dimension	Mean *(SD)*	Range
Ease of use for teachers	4.80 (0.15)	4.5–5.0
Student engagement and participation	4.70 (0.18)	4.4–5.0
Feasibility within classroom time	4.45 (0.25)	4.0–4.9
Overall	4.65 (0.19)	4.3–5.0

These high scores suggest that the model is well-designed for classroom implementation, although some challenges were identified in time management and resource adaptability. Teachers found the model particularly effective for fostering student engagement, as it encouraged active participation and collaboration through ethnoscience projects and problem-solving activities.

Qualitative data collected through teacher interviews and classroom observations provided a deeper understanding of the model's practicality. Teachers unanimously agreed that the model was engaging and manageable with adequate preparation and training. One teacher shared, "This is one of the few models that truly motivates students. They were excited to explore their local culture and connect it to science concepts" (Teacher 9). This aligns with the high scores for student engagement and participation.

Another teacher noted, "The step-by-step structure of the model made it easy for me to follow, even though I had no prior experience with Blended Learning" (Teacher 7). This reinforces the high score for ease of use, emphasizing the model's clear and teacher-friendly design.

However, the dimension of feasibility within classroom time received a relatively lower score, reflecting challenges in managing activities within a standard class period. One teacher explained, "Initially, I struggled to balance the face-to-face and online components, but after a few sessions, I learned how to streamline the process" (Teacher 3). This suggests that while the model requires an initial learning curve, its practicality improves with experience.

Variations in student engagement were observed across different contexts, particularly between urban and rural schools. In urban settings, students actively participated in digital activities, with one teacher commenting, "The use of online platforms like video tutorials and interactive quizzes kept students engaged throughout" (Teacher 4). Conversely, teachers in rural areas reported challenges due to intermittent internet access, requiring them to adapt the model. One teacher described, "We prepared offline versions of the digital content such as printed worksheets and videos on USB drives, which helped maintain students' interest despite the connectivity issues" (Teacher 7).

Students' enthusiasm for ethnoscience projects was another recurring theme. A teacher shared,

> When we explored local traditional medicine practices as part of the project, students were eager to interview elders and bring their findings back to the classroom. This not only enhanced their learning but also strengthened their connection to their community. (Teacher 5)

This feedback underscores the model's strength in contextualizing learning and fostering cultural appreciation.

The combination of quantitative and qualitative data reveals that the Blended-PBL model is highly practical for classroom use, with particular strengths in student engagement and ease of implementation. The findings also highlight specific areas for improvement such as refining the timing of activities and ensuring access to digital resources in rural settings. While the quantitative results demonstrate the model's robustness, the qualitative insights provide valuable context, showing how teachers adapted the model to overcome challenges.

Overall, the model proved to be a feasible and engaging approach to integrating ethnoscience into science education. Its flexibility allowed teachers to tailor the

implementation to their specific classroom environments, ensuring that students across diverse contexts could benefit from its innovative approach.

3.3 Effectiveness of the Blended-PBL Model in Improving 21st-Century Skills

The effectiveness of the Blended-PBL model was assessed using pre- and post-tests that were designed to evaluate students' critical thinking, communication, and creativity skills. The results shown in Table 4 indicate significant improvements across all dimensions with large effect sizes (*Cohen's d* > 1.30), demonstrating the model's capacity to enhance 21st-century skills.

Table 4: Pre- and post-test results for 21st-century skills

Skill	Pre-Test Mean (*SD*)	Post-Test Mean (*SD*)	*t*	*p*	Effect Size (*Cohen's d*)
Critical Thinking	62.15 (6.45)	78.50 (5.85)	12.23	<0.001	1.47
Communication	65.20 (5.98)	80.25 (6.15)	10.85	<0.001	1.35
Creativity	58.30 (6.85)	74.80 (6.55)	11.92	<0.001	1.43

The greatest improvements were observed in critical thinking, with a mean increase of 16.35 points, followed by creativity (16.50 points) and communication (15.05 points). The consistent improvements across all skill dimensions suggested the effectiveness of the model in creating an engaging and interactive learning environment. These gains were most pronounced in urban and suburban schools where students benefited from greater access to digital resources and stable internet connectivity. Effect sizes of $d > 1.30$ indicated a large impact, confirming the model's effectiveness in fostering critical thinking, communication, and creativity.

To complement the quantitative results, qualitative data were gathered through student focus groups, teacher interviews, and classroom observations. These data provided nuanced insights into how the Blended-PBL model fostered critical thinking, communication, and creativity while also identifying contextual factors influencing its impact.

Students were overwhelmingly positive about the ethnoscience integration, which they found both engaging and meaningful. One student remarked, "The project on traditional food preservation was eye-opening. It made me think critically about how science is part of our culture and daily life" (Student 13). Another stated, "The teamwork activities improved my communication skills because I had to explain my ideas clearly to my group" (Student 11). These comments reflect the model's ability to make abstract scientific concepts tangible and to promote active collaboration.

However, a few students struggled initially with the problem-solving process, highlighting the need for teacher guidance. One student explained, "At first, I didn't know how to approach the problem, but the teacher's step-by-step instructions really helped" (Student 4). This indicates that while the model

encourages independent thinking, it also requires effective scaffolding from educators to support students in navigating the learning process.

Teachers corroborated these observations, noting marked changes in student engagement and participation. One teacher shared, "Even students who were usually disengaged became active participants because they were excited to explore their cultural heritage and present their findings" (Teacher 9). Another commented, "The communication tasks, like group presentations, boosted students' confidence in speaking and explaining their ideas" (Teacher 1).

Challenges were observed in fostering creativity in rural schools, primarily due to limited access to diverse resources. A rural teacher explained, "Students were less exposed to examples of creative projects, so we had to provide more visual aids and examples to inspire them" (Teacher 5). Despite these challenges, teachers reported that even in resource-limited settings, students displayed significant improvements in creativity through ethnoscience-based projects.

Classroom observations further validated these findings. In urban settings, students actively used online tools such as interactive quizzes and multimedia resources, while in rural areas, adaptations such as printed materials and locally available resources ensured participation. For instance, one rural classroom adapted a digital task by incorporating a hands-on project on traditional herbal medicines, which students then documented in written and illustrated reports.

The quantitative data demonstrate the effectiveness of the Blended-PBL model in fostering critical thinking, communication, and creativity, with large improvements across all dimensions. The qualitative data provide additional depth, illustrating how the model's ethnoscience projects engaged students and supported skill development. The alignment between quantitative improvements and qualitative feedback suggests that the model's interactive, culturally responsive approach effectively meets its educational objectives.

However, the findings also highlight contextual challenges, particularly in rural areas. Limited access to digital tools affected the ease with which students could develop creativity, unlike their urban counterparts. Nonetheless, the adaptations made by the teachers ensured that students in these rural settings could still benefit significantly from the model. Overall, the Blended-PBL model proved to be a powerful tool for enhancing 21st-century skills. Its effectiveness was rooted in its ability to combine active learning strategies with culturally meaningful content, fostering not only academic growth but also a deeper appreciation for students' cultural heritage.

4. Discussion

The findings of this study demonstrate the validity, practicality, and effectiveness of the Blended-PBL model with ethnoscience integration in enhancing critical thinking, communication, and creativity among junior high school students. These findings align with existing literature on the Blended-PBL and ethnoscience

and offer unique insights into the integration of cultural elements within modern pedagogical frameworks.

The high validity scores from expert evaluations confirm the robustness of the model's design, particularly its alignment with 21st-century educational goals and its incorporation of ethnoscience. This aligns with the theoretical propositions of Hamsiah (2023) who emphasizes the adaptability of Blended Learning in diverse educational contexts and Barrows (1986), whose PBL approach underscores the importance of active, inquiry-driven learning. Moreover, the integration of ethnoscience validates claims by Anane (2023) that cultural relevance enhances student engagement and learning outcomes. However, the slightly lower scores for technological accessibility highlight the challenges identified by Creswell and Poth (2016) who noted the digital divide as a persistent issue in educational innovation. This finding aligns with Creswell and Poth's (2016) assertion that culturally relevant instructional strategies enhance engagement and learning outcomes. This study contributes to this discourse by proposing adaptations such as offline resources to mitigate these challenges, thereby addressing gaps in the literature on inclusive educational practices.

The practical findings underscore the model's feasibility and its positive reception among teachers and students. Teachers found the model's structure intuitive and supportive, which aligns with previous studies that emphasize the importance of well-designed instructional frameworks (Plomp, 2013). Student engagement, particularly through ethnoscience projects, mirrors the findings of Fitria et al. (2024) who reported increased student motivation in PBL environments enriched by contextualized materials. However, this study extends the literature by highlighting the adaptability of Blended-PBL in diverse settings, including rural classrooms with limited digital infrastructure. Unlike prior studies that primarily focus on urban or resource-rich settings, this research demonstrates how ethnoscience can act as a bridge, enabling meaningful learning even in resource-constrained environments.

The significant improvements in critical thinking, communication, and creativity corroborate the effectiveness of Blended-PBL in developing 21st-century skills. The gains in critical thinking reflect the findings of Facione (2011) who linked problem-based approaches to enhanced cognitive abilities. Similarly, the improvement in communication aligns with the assertion of Murray et al. (2024) that collaborative tasks in blended environments foster interpersonal skills. The creativity gains resonate with the conclusions of Amin et al. (2020) regarding the potential of PBL to encourage innovative thinking. However, the current study adds to the existing body of knowledge by illustrating how the inclusion of ethnoscience uniquely amplifies these skills. By engaging students in culturally meaningful projects, the model not only enhances their academic capabilities but also fosters a deeper connection to their heritage. This dual benefit—academic and cultural—is a distinctive contribution of the study, addressing calls by Susanto (2023) for more culturally responsive teaching practices within the Merdeka Curriculum framework.

Despite alignment with much of the literature, certain aspects diverge. For instance, the feedback from the rural teachers on the challenges of fostering creativity with limited exposure to diverse resources contrasts with studies such as that of Kusumawardani and Aminatun (2024), which assumes uniform access to materials. The findings of this study suggest that creativity in rural contexts requires additional scaffolding and tailored resources, thus contributing new insights into how PBL models can be adapted for equity. Furthermore, the emphasis on the ethnoscience dimension provides a unique lens that is often overlooked in Blended Learning and PBL research (Sunarti et al., 2024; Verawati & Nisrina, 2025). While existing studies have explored cultural contexts in education, few have systematically integrated them into a blended framework, making this study a valuable addition to the field.

The theoretical implications of the findings highlight the model's alignment with constructivist theories that emphasize the importance of active, student-centered learning and real-world applications (Dewey, 1986; Zainil et al., 2024). The inclusion of ethnoscience as a core element enriches this framework, demonstrating how culturally embedded knowledge systems can serve as scaffolds for learning. This aligns with Fogarty's (1991) integrated curriculum models, particularly those emphasizing thematic and interdisciplinary learning. The study also supports Alblooshi's (2021) assertion that 21st-century learning must transcend traditional disciplinary boundaries and integrate technology, cultural context, and collaborative problem-solving. Insights from ethnoscience integration in African and Asian classrooms reveal the potential for this model to be adapted across cultural contexts.

In terms of its unique contributions, this study advances the discourse on Blended-PBL by demonstrating its feasibility and effectiveness in culturally diverse and resource-constrained settings. It introduces ethnoscience as a pivotal element, enriching both academic and cultural outcomes. The model can be adjusted by incorporating locally relevant ethnoscience practices and offline teaching resources to address infrastructure disparities (Putri et al., 2024; Yusof et al., 2024). Moreover, the study provides a practical blueprint for adapting blended models to rural contexts, addressing a critical gap in the literature. By offering strategies to bridge digital divides and tailor resources, it sets a precedent for inclusive educational practices. This study contributes a framework for integrating culturally relevant pedagogies into science education, offering insights for educators and policymakers to enhance teaching strategies globally. Limited digital infrastructure in rural schools posed challenges for online components of the Blended-PBL model. Solutions such as offline resources and teacher-led adaptations mitigated these issues (Perry et al., 2021; Waty et al., 2023). Future studies could incorporate observational methods or third-party assessments to mitigate the bias that is inherent in self-reported data. Longitudinal studies could provide deeper insights into the sustained impact of the model on 21st-century skills development.

Overall, the findings reaffirm the potential of Blended-PBL with ethnoscience integration to transform science education, aligning with both theoretical and

practical imperatives. The current study bridges global pedagogical trends with local contexts, offering a model that is not only innovative but also culturally resonant and adaptable to diverse educational landscapes. This unique blend of academic rigor and cultural relevance positions the study as a significant contribution to the field of educational research. The model's integration of ethnoscience has the potential to foster lifelong cultural appreciation and adaptability, equipping students with skills for both academic and real-world challenges (Handrianto et al., 2023; El-Yazidi & Rijal, 2024).

5. Conclusion

This study's investigation of the Blended-PBL model with ethnoscience integration yielded significant findings across all three research questions: the model demonstrated high validity in theoretical and practical considerations; showed strong practicality in classroom implementation despite some technological challenges in rural areas; and effectively enhanced students' 21st-century skills with large effect sizes across critical thinking, communication, and creativity. The model demonstrates significant potential for addressing educational challenges. The research has important implications for educational practice, suggesting that culturally responsive Blended Learning can successfully bridge traditional and modern pedagogical approaches and foster essential skills. Moreover, this research underscores the potential of culturally responsive Blended Learning to bridge traditional and modern pedagogies in diverse educational settings. The model demonstrates strong potential for scalability in both resource-rich and resource-constrained settings. However, limitations such as the digital divide in rural areas and the relatively short implementation period should be noted. Future research should explore longitudinal effects, investigate scalability across different cultural contexts, and develop more adaptive solutions for resource-constrained settings, particularly focusing on sustainable approaches to overcome technological barriers in rural schools.

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