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Developing an Indigenous Knowledge-Oriented Instructional Module to Support Biodiversity Literacy and Team Communication Skills Using the ADDIE Model

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ABSTRACT

Background: Biodiversity loss requires students to develop biodiversity literacy (BL), including biodiversity knowledge (BK) and biodiversity awareness (BA), while also fostering team communication skills (TCS). Indigenous knowledge may provide a meaningful context for achieving these learning outcomes. **Objectives:** This study aimed to develop and evaluate an instructional module integrating the indigenous knowledge of the Somongari Javanese community with Project-Based Learning (IKIM-PBL) to support BL and TCS. **Design:** This study employed a development research design using the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate). **Setting and Participants:** The study was conducted at Bruderan Purworejo High School and Somongari Village, Indonesia. Participants varied across the ADDIE phases and included students, expert validators, and one biology teacher. **Data Collection and Analysis**: Data were collected using expert validation sheets, questionnaires, interviews, observations, and pre- and post-tests. Descriptive statistics evaluated module validity and practicality, while paired-samples *t*-tests and Wilcoxon signed-rank tests examined students' learning outcomes. **Results:** The IKIM-PBL module was judged valid and practical for classroom implementation. The proportion of students in the low category decreased from 96.00% to 48.00% for BK, from 68.00% to 24.00% for BA, and from 48.00% to 20.00% for TCS. Inferential analyses indicated statistically significant improvements in BK and BA (both $p < .001$). Although the improvement in TCS was not statistically significant ($p = .056$), it demonstrated a medium effect size ($r = 0.38$). **Conclusions:** The IKIM-PBL module provides a valid and practical instructional resource for biodiversity education. Integrating indigenous knowledge with Project-Based Learning significantly improved biodiversity knowledge and biodiversity awareness, while showing potential to strengthen team communication skills.

Keywords: biodiversity awareness; biodiversity knowledge; biodiversity literacy; indigenous knowledge; instructional module; project-based learning; team communication skills.

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Desenvolvimento de um Módulo Instrucional Orientado pelo Conhecimento Indígena para Apoiar a Alfabetização em Biodiversidade e as Habilidades de Comunicação em Equipe Utilizando o Modelo ADDIE

RESUMO

Contexto: A perda da biodiversidade exige que os estudantes desenvolvam a alfabetização em biodiversidade (BL), que inclui o conhecimento sobre biodiversidade (BK) e a conscientização sobre biodiversidade (BA), além de promover habilidades de comunicação em equipe (TCS). A integração do conhecimento indígena ao ensino da biodiversidade pode proporcionar uma aprendizagem contextualizada e significativa.**Objetivos:** Este estudo teve como objetivo desenvolver e avaliar um módulo instrucional que integra o conhecimento indígena da comunidade javanesa de Somongari com a Aprendizagem Baseada em Projetos (IKIM-PBL) para promover a alfabetização em biodiversidade e as habilidades de comunicação em equipe. **Desenho:** Este estudo adotou um delineamento de pesquisa de desenvolvimento utilizando o modelo ADDIE (Análise, Design, Desenvolvimento, Implementação e Avaliação). **Contexto e Participantes:** O estudo foi realizado na Escola Secundária Bruderan Purworejo e na Vila de Somongari, Indonésia. Participaram diferentes grupos ao longo das fases do modelo ADDIE, incluindo estudantes, especialistas avaliadores e um professor de Biologia. **Coleta e Análise dos Dados:** Os dados foram coletados por meio de instrumentos de validação por especialistas, questionários, entrevistas, observações e testes aplicados antes e após a intervenção. Foram utilizadas estatísticas descritivas para avaliar a validade e a praticidade do módulo, enquanto o teste *t* pareado e o teste dos postos sinalizados de Wilcoxon foram empregados para analisar os resultados de aprendizagem. **Resultados:** O módulo IKIM-PBL foi considerado válido e prático para implementação em sala de aula. A proporção de estudantes classificados na categoria baixa diminuiu de 96,00% para 48,00% no conhecimento sobre biodiversidade (BK), de 68,00% para 24,00% na conscientização sobre biodiversidade (BA) e de 48,00% para 20,00% nas habilidades de comunicação em equipe (TCS). As análises inferenciais indicaram melhorias estatisticamente significativas no conhecimento sobre biodiversidade (BK) e na conscientização sobre biodiversidade (BA) (ambos $p < 0{,}001$). Embora a melhoria nas habilidades de comunicação em equipe (TCS) não tenha sido estatisticamente significativa ($p = 0{,}056$), foi observado um tamanho de efeito moderado ($r = 0{,}38$). **Conclusões:** O módulo IKIM-PBL constitui um recurso didático válido e prático para a educação em biodiversidade. A integração do conhecimento indígena com a Aprendizagem Baseada em Projetos promoveu melhorias significativas no conhecimento sobre biodiversidade e na conscientização sobre biodiversidade, ao mesmo tempo em que demonstrou potencial para fortalecer as habilidades de comunicação em equipe.

Palavras-chave: alfabetização em biodiversidade; aprendizagem baseada em projetos; conhecimento indígena; habilidades de comunicação em equipe; módulo instrucional.

INTRODUCTION

Biodiversity is declining on Earth, accompanied by a lack of biodiversity literacy. Biodiversity literacy (BL) refers to the knowledge (BK) and awareness of biodiversity (BA). Research has shown that young people lack biodiversity literacy (Barrutia et al., 2022; Pedrera et al., 2021), as evidenced by their lack of understanding of the value of plants (Pedrera et al., 2021), difficulty in comprehending diversity levels (Schneiderhan-Opel & Bogner, 2020), and limited knowledge of animal species (Hooykaas et al., 2019; Randler & Heil, 2021).

Contributing factors to the lack of biodiversity literacy among students include the absence of individual participation in biodiversity-related activities (Hooykaas et al., 2020), changes in curriculum (Gerl et al., 2021), and insufficient species identification skills (Paradise & Bartkovich, 2021). Biodiversity literacy is crucial, as it enhances students' comprehension of the significance of biodiversity (Moss et al., 2014) and their knowledge of species diversity (Barrutia et al., 2022). Furthermore, students can positively perceive biodiversity through its influence (Paradise & Bartkovich, 2021).

Therefore, improving biodiversity literacy requires instructional approaches that connect conceptual knowledge with authentic biodiversity contexts and actively engage students in meaningful learning experiences. However, many existing instructional approaches still emphasize conceptual understanding while providing limited opportunities for students to engage directly with authentic biodiversity contexts and local environmental issues. Given these challenges, biodiversity literacy should not be viewed merely as the acquisition of biological concepts but as part of broader scientific literacy that enables students to understand and respond to real-world biodiversity issues.

Biodiversity literacy (BL) is aligned with scientific literacy, which provides an understanding of socio-scientific issues (Holbrook and Rannikmae, 2009), such as biodiversity and the environment (Kamudu et al., 2022). One of the primary objectives of educational research is to enhance scientific literacy in the instructional process (Djamahar et al., 2018), namely, collaboration and communication (Norris, 2019). Not all students have good team communication skills. Poor communication is common among students (Albalawi & Nadeem, 2020) due to insecurity, self-centeredness, gossip, and language (Yildiz & Tutkun, 2021), lack of teamwork experience (Allert et al., 2022), and team role composition (Palyga, 2018).

Poor communication undermines team communication skills (TCS). Team communication skills (TCS) are active listening, discussion, nonverbal communication, argumentation, and feedback (Allert et al., 2022). TCS includes three areas: closed-loop communication (CLT), information exchange (IE), and listening activity (LA) (Nelson, 2018). Because biodiversity issues are often addressed through collaborative inquiry and problem-solving, biodiversity literacy and team communication skills should be developed simultaneously rather than as separate learning outcomes.

Today's education needs biodiversity literacy and team communication skills to prevent biodiversity loss and support 21st-century learning. This demand aligns with SDG target 15 on life on land (terrestrial ecosystems) and SDG target 4 on quality education (United Nations, 2015). This demand also aligns with the Aichi Biodiversity Targets document, which mainly targets 1 and 2 on awareness of the value of biodiversity (CBD, 2013). Learning innovation can be achieved by incorporating indigenous knowledge into the study of biodiversity issues. Biodiversity and indigenous knowledge are closely linked.

Indigenous knowledge (IK) is the principles, skills, practices, rituals, and customs developed by specific races and tribes and passed down from generation to generation (Adam et al., 2019; Ksenofontov et al., 2019). Indigenous knowledge is often found in areas rich in biodiversity and occupied by specific ethnic/tribal groups (Adam, 2019; Gonçalves et al., 2021), including Javanese communities in Somongari Village, Kaligesing Subdistrict, Purworejo Regency, Indonesia. From January to August 2022, observations revealed several traditions in the village, including traditional rituals, coconut sugar production, and local taxonomy of animals associated with coconut trees.

The current demand is to elaborate on biodiversity and indigenous knowledge in environmental education to accommodate BL and TCS. Research related to the integration of indigenous knowledge and biodiversity in high school has been conducted by several researchers. In research by Sumarni et al. (2022), the scientific concept in the manufacture of traditional medicine has essential implications for indigenizing the science curriculum in Indonesia, oriented towards ethno-STEM. Hopkins (2019) argued that Indigenous knowledge provides perspectives that can address questions that may not emerge within Western knowledge systems alone, thereby creating opportunities for multiple ways of knowing to enrich science learning. Although these studies demonstrate the educational value of indigenous knowledge, they primarily emphasize curriculum integration or conceptual perspectives rather than the systematic development and evaluation of instructional modules that simultaneously promote biodiversity literacy and team communication skills. Consequently, there remains a need for instructional materials that integrate indigenous knowledge with project-based learning through a systematic instructional design process.

To address this need, Project-Based Learning (PBL) offers opportunities to integrate indigenous knowledge into authentic and collaborative learning experiences. BL and TCS can be realized through PBL. Until this paper was written, no environmental education in Somongari Village integrated biodiversity learning with IK through PBL. Students' relationships and interactions with nature and biodiversity can be facilitated through PBL (Adigun, 2020). PBL is preceded by problem-solving with a product at the end (Bender, 2012). However, to the best of our knowledge, no previous study has developed and evaluated an Indigenous Knowledge-oriented instructional module based on the ADDIE model that integrates the biodiversity of Somongari Village into project-based learning while simultaneously supporting biodiversity literacy and team communication skills. Accordingly, this study aimed to develop and evaluate such an instructional module using the ADDIE model.

This study aimed to develop an Indigenous Knowledge-oriented Instructional Module integrated with Project-Based Learning (IKIM-PBL) using the ADDIE instructional design model to support BL and TCS. The development of this module is essential because instructional modules serve as learning resources that promote students' independent learning by providing clearly defined learning objectives, structured learning activities, instructional guidance, and evaluation components (Robinson & Crittenden, 1972; Utomo et al., 2020). Moreover, instructional modules have been shown to enhance students' motivation to learn (Syafii & Yasin, 2013), reduce learning anxiety (Yang et al., 2021), and improve learning skills and academic achievement (Haris & Osman, 2015). Accordingly, this study addressed the following research questions: (1) What are the instructional characteristics of the IKIM-PBL module developed using the ADDIE model? (2) How valid and practical is the developed IKIM-PBL module? Moreover, (3) How does the implementation of the developed module support students' BL and TCS?

METHODS

The research was conducted from September 2022 to September 2023 at Bruderan Purworejo High School, Indonesia. The research method used was the development method, based on the ADDIE phase concept. This phase comprises five phases: analyze, design, develop, implement, and evaluate (Branch, 2009).

Analyze Phase. Purpose: To identify performance gaps related to biodiversity literacy (BL) and team communication skills (TCS). Data collection: Data were collected from 30 Grade X students at Bruderan Purworejo High School using tests of species knowledge (10 items), biodiversity knowledge (20 items), biodiversity awareness (2 items), and collaboration (1 item). Data analysis: Data were analyzed descriptively using the performance criteria proposed by Briggs et al. (2023).

Design Phase. Purpose: To verify desired performance and appropriate test methods, including conducting task inventories, developing performance objectives, creating test strategies, and calculating return on investment. Data collection: qualitative about the design of student activities in the instructional module. Data analysis: Describe the content of the instructional module.

Develop Phase. Purpose: To produce and validate the selected learning resources, including developing the instructional content, supporting media, student and teacher guides, conducting formative revisions, and piloting. Data collection: instructional module validation and research instruments were evaluated through expert review, followed by formative evaluation consisting of a one-to-one trial (6 students), a small-group trial (16 students), a field trial (16 students), and a pilot test (16 students) using pre-test–post-test procedures, observations, and questionnaires. Data analysis: Descriptive statistics were used to summarize the expert validation results, formative evaluation outcomes, and questionnaire responses. The findings from the formative evaluation were used to revise and improve the module before implementation.

Implement Phase. Purpose: To prepare the learning environment and implement the developed IKIM-PBL module. The implementation phase employed a one-group pre-test–post-test design involving 25 students. Data collection: qualitative data on the implementation of learning activities were collected through classroom observations and student interviews. Data analysis: descriptive qualitative analysis was used to summarize the implementation process.

Evaluate Phase. Purpose: To evaluate the quality and effectiveness of the developed IKIM-PBL module following its implementation. Data collection: BL scores consisting of BK using a multiple-choice test (23 items), BA using a Likert-scale questionnaire (30 items), and TCS using a Likert-scale questionnaire (23 items). Data analysis: Descriptive statistics were used to summarize the results. The normality of the difference scores (post-test minus pre-test) was assessed using the Shapiro–Wilk test (Field, 2018). Variables with normally distributed difference scores were analyzed using the paired-samples t-test, whereas variables with non-normally distributed difference scores were analyzed using the Wilcoxon signed-rank test. Effect sizes were calculated to assess the magnitude of the intervention effects, with Cohen's d reported for paired-samples t-tests and the effect size (r) for Wilcoxon signed-rank tests (Field, 2018). Effect sizes were interpreted according to J. Cohen's (1988) conventions. Statistical significance was set at $p < .05$.

RESULTS AND DISCUSSION

Analyze Phase

The analyze phase identified several performance gaps related to BL and TCS. Students demonstrated low species knowledge, with an average score of 60.00% (low category), and 66.66% of students were classified as low. Biodiversity knowledge was also low, with an average score of 46.33%, and 93.34% of students classified as having low knowledge. Likewise, biodiversity awareness reached only 52.50%, with 73.33% of students falling into the low category. In addition, students had limited experience with collaborative learning because classroom activities were predominantly individual rather than project-based. Consequently, opportunities to develop TCS were limited. These findings indicate that insufficient BL activities and collaborative learning experiences constituted the main performance gaps that needed to be addressed.

Based on these identified needs, the instructional goals were formulated to improve students' biodiversity literacy (BL), including biodiversity knowledge (BK) and biodiversity awareness (BA), together with team communication skills (TCS) through the development of the Indigenous Knowledge-oriented Instructional Module integrated with Project-Based Learning (IKIM-PBL). The analysis phase also identified the content, technological, instructional, and human resources required for module development.

Design Phase

In the design phase, the instructional goals identified during the analysis phase were translated into specific learning objectives, performance indicators, and instructional activities following the ADDIE instructional design model by Branch (2009). These objectives also guided the development of the assessment instruments used to evaluate students' BL and TCS. BL was developed based on the framework proposed by WWF and WCEE (1996), whereas TCS were adapted from Nelson (2018).

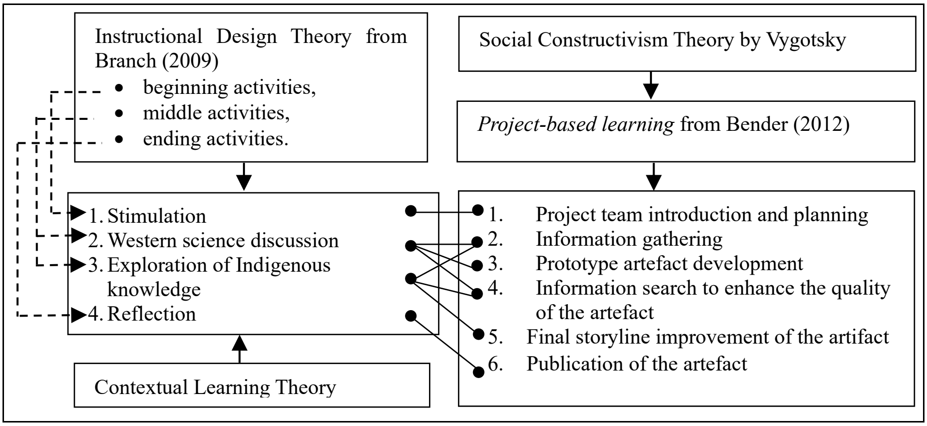
The instructional strategy integrated the indigenous knowledge of the Somongari Javanese community with Western science through Project-Based Learning (PBL). The PBL framework adopted by Bender (2012) includes six stages: project introduction and planning, information gathering, prototype development, information refinement, storyboard improvement, and artifact publication. This instructional strategy was grounded in Vygotsky's (1978) social constructivist theory, which emphasizes collaborative knowledge construction through authentic learning experiences.

The IKIM-PBL module was subsequently organized by integrating these PBL stages with Branch's (2009) instructional design framework, which consists of beginning, middle, and ending instructional activities. This integration resulted in four instructional steps implemented in each learning activity: (1) stimulation, (2) Western science discussion, (3) indigenous knowledge exploration, and (4) reflection. These instructional steps were designed within a contextual learning approach to connect scientific concepts with students' real-life experiences in the Somongari community. The theoretical framework underpinning the instructional design is presented in Figure 1.

The stimulation stage was designed to activate students' prior knowledge and prepare them for subsequent learning activities. Piaget's cognitive theory informed the stimulation stage to activate students' prior knowledge (Piaget's, 1952); Vygotsky's social constructivist theory to facilitate learning through social interaction (Vygotsky, 1978); Pavlov's classical conditioning theory to attract students' attention through meaningful learning stimuli (Pavlov, 1927), and Skinner's behaviorist theory to reinforce students' active engagement during learning (Skinner, 1938).

Figure 1

Activity Design for Instructional Modules



The Western science discussion was designed to strengthen students' scientific understanding of biodiversity through critical engagement with contemporary scientific concepts. In this study, the term "Western science" is used, following Cohen (2010), to refer to the modern scientific tradition as it is taught in contemporary science education. Accordingly, the biodiversity content was developed from scientific reference books, journal articles, and internationally recognized educational and conservation frameworks, including the Next Generation Science Standards (NGSS et al., 2013), the Sustainable Development Goals (United Nations, 2015), and the Aichi Biodiversity Targets (CBD, 2013). The integration of Western science and indigenous knowledge was intended to provide complementary perspectives for understanding biodiversity and its conservation (Chakrabarty et al., 2023; Wilder et al., 2016).

The indigenous knowledge (IK) exploration stage engaged students in investigating the use of plants and animals in traditional rituals, traditional coconut sugar production, and the utilization of local biodiversity in the Somongari community. Indigenous knowledge provides valuable insights into local biodiversity practices (Baul & McDonald, 2014; Malekani, 2020; Singh et al., 2015) and is transmitted across generations through social communication (Ksenofontov et al., 2019). In addition to ecological knowledge, IK also promotes cultural values, mutual respect, and ethical behavior (Singh, 2019), enabling students to develop contextual understanding grounded in their surrounding cultural experiences(Triyanto & Handayani, 2020).

The Western science discussion and indigenous knowledge exploration were designed based on Piaget's cognitive learning theory, Vygotsky's social constructivist theory, Bandura's social learning theory, and contextual learning. These learning activities encouraged students to actively construct knowledge through critical discussion, collaborative learning, observation, and authentic field experiences (Piaget, 1952; Vygotsky, 1978; Bandura, 1977). By connecting scientific concepts with biodiversity practices in Somongari Village, students were expected to relate classroom knowledge to real-world situations, which is a key principle of contextual learning (Westera, 2011).

Reflection was conducted at the end of each learning activity to encourage students to connect newly acquired knowledge with their prior experiences, evaluate their understanding, and consolidate learning. This stage was informed by Vygotsky's social constructivist theory and Bandura's social learning theory, emphasizing reflection, social interaction, and self-regulation in the learning process (Vygotsky, 1978; Bandura, 1977). The reflection activities also aligned with recommendations for effective biology instruction that integrates content, pedagogy, and instructional materials (Orbeta, 2022).

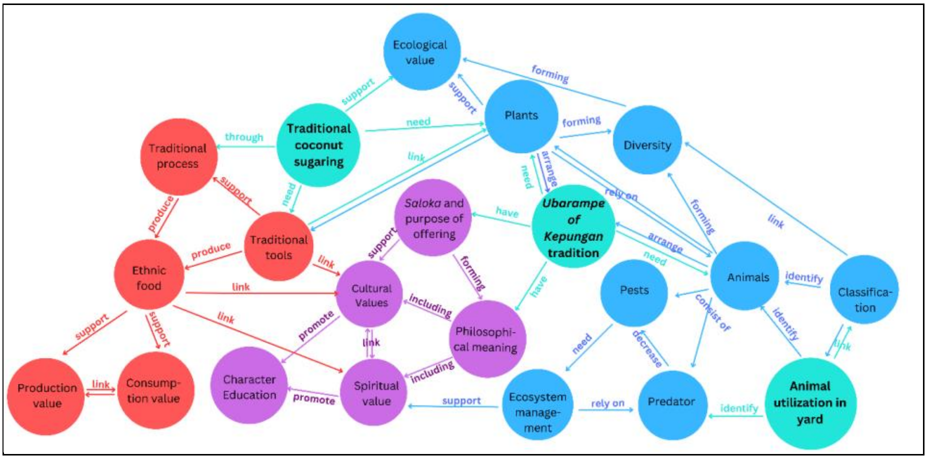
Develop Phase

IKIM-PBL was successfully developed as an instructional module that systematically integrates Western science with the indigenous knowledge of the Somongari Javanese community. The module consists of three learning activities focusing on biodiversity through traditional rituals, traditional agriculture, and biodiversity conservation. Each learning activity is designed to connect scientific concepts with authentic local practices, enabling students to explore biodiversity from both scientific and indigenous perspectives. The conceptual integration of indigenous knowledge and Western science that underpins the instructional design is presented in Figure 2. To facilitate broader dissemination and future implementation, the developed module is publicly available at https://bit.ly/biodiversityindigenous (Adinugraha et al., 2023).

Figure 2 illustrates the conceptual relationships between indigenous knowledge themes and Western biological concepts embedded in the IKIM-PBL module. Traditional rituals, coconut sugar production, and the utilization of local biodiversity are linked to concepts of biodiversity, taxonomy, ecological values, cultural values, and sustainability. This conceptual framework serves as the foundation for designing learning activities that integrate indigenous knowledge with scientific concepts in a coherent and interdisciplinary manner.

Figure 2

Conceptual integration of Somongari Javanese indigenous knowledge and Western science in the IKIM-PBL module



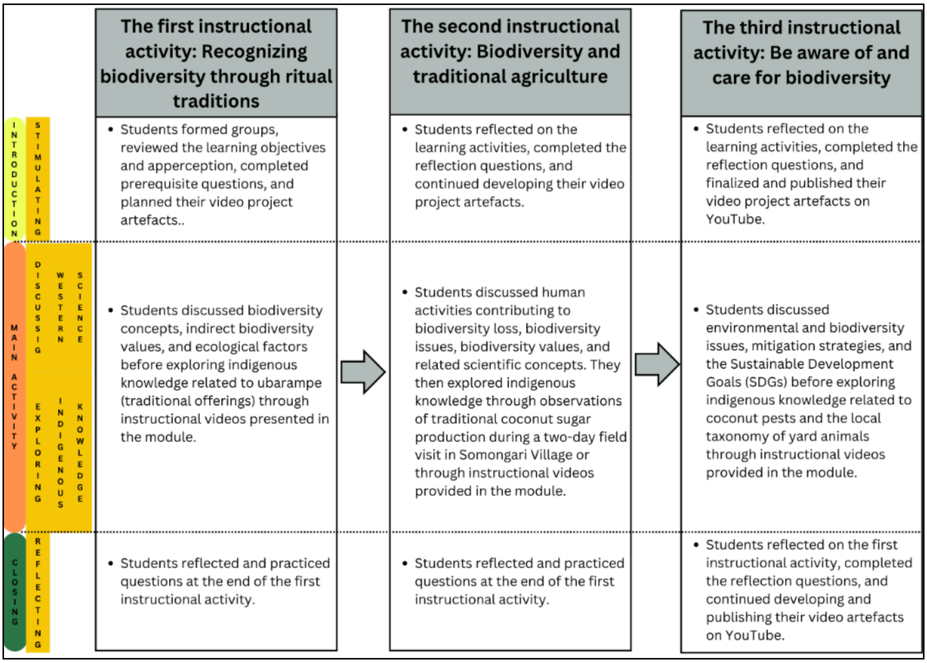
Expert Validation

Content validation was conducted by three experts, comprising a biology education expert, an ethnobotany and biodiversity expert, and an environmental science expert. Overall, the experts confirmed that the developed IKIM-PBL module was suitable for classroom implementation, subject to minor revisions. The module received excellent ratings across all evaluation components, including moral legality, content feasibility, presentation, language, and module characteristics, each obtaining a score of 100%. The module structure received a score of 90%, resulting in an overall mean validity score of 98.33%, which falls within the "highly feasible" category (Sutama et al., 2020). The lower score for the module structure reflected several incomplete components in the draft version, such as the index, publication page, and back cover, which were subsequently revised before the formative evaluation.

The developed module incorporates key instructional characteristics, including an attractive layout, communicative language, the integration of Western science and indigenous knowledge, constructivist learning, literacy-oriented activities, 21st-century skills, and character education. As shown in Figure 3, these characteristics are implemented through three sequential learning activities that culminate in a biodiversity-based video project.

Figure 3

Learning Sequence of the Indigenous Knowledge-Oriented Instructional Module (IKIM-PBL)



The development phase was evaluated through four sequential stages: one-to-one evaluation, small-group evaluation, field trial, and pilot testing. These formative evaluations were conducted to refine the module by examining its usability, clarity, practicality, and students' perceptions before implementation.

One-to-one Trial

A one-to-one trial involving six students was conducted to evaluate the usability of the developed module during a simulated learning activity in Somongari Village. Overall, the students responded positively to IKIM-PBL and considered the module easy to understand and use. The primary suggestion was to include educational videos to support independent learning and facilitate review outside the classroom. Based on this feedback, educational videos were incorporated into the revised module before the small-group trial.

Small-group Trial

A small-group trial involving 16 students was conducted to assess the preliminary performance of the revised module prior to classroom implementation. The distribution of students shifted toward higher achievement levels after the intervention. In BK, the proportion of students in the high and moderate categories increased from 0% to 6.25% and from 0% to 18.75%, respectively, while the low category decreased from 100% to 75%. Similarly, for BA, the proportion of students in the moderate category increased from 56.25% to 68.75%, accompanied by a reduction in the low category from 18.75% to 12.50%, although the high category decreased slightly from 25.00% to 18.75%. TCS also improved, with the proportion of students in the high and moderate categories increasing from 18.75% to 25.00% and from 25.00% to 62.50%, respectively, while the low category decreased substantially from 56.25% to 12.50%. Overall, these findings suggest that the revised IKIM-PBL module demonstrated promising preliminary performance and was suitable for subsequent classroom implementation.

Field Trial

A field trial with 16 students was conducted to evaluate the technical implementation of the revised IKIM-PBL module under authentic learning conditions prior to the main implementation phase. The learning activities were successfully conducted in both classroom and village settings over a two-day, one-night program in Somongari Village. Students completed all PBL activities in accordance with the module procedures, including classroom discussions, field exploration, indigenous knowledge documentation, collaborative data analysis, and educational video production. The field trial demonstrated that the developed module was technically feasible for implementation in authentic learning environments and required no major revisions prior to classroom implementation.

Pilot Test

Following the field trial, a pilot test was conducted to evaluate students' perceptions of the learning activities, the quality of the IKIM-PBL module, and its instructional characteristics. 81.25% of students reported positive or very positive perceptions of the learning activities. In comparison, all students (100%) expressed positive or very positive perceptions of both the module quality and its instructional characteristics. The highest ratings were for the module's instructional characteristics, indicating that students perceived the integration of indigenous knowledge and project-based learning as relevant and engaging. Overall, these findings suggest that the developed module was appropriate for classroom implementation.

Implement Phase

The implementation phase involved 25 Grade 10 students during the first semester of the 2023/2024 academic year under the guidance of one biology teacher. The revised IKIM-PBL module, refined during the development phase, was implemented through eight learning sessions, including seven classroom meetings and one field-based learning activity in Somongari Village. During the field activity, students spent two days and one night in the village to explore local biodiversity and indigenous knowledge through authentic learning experiences. The learning process concluded with group artefacts in the form of educational videos documenting the indigenous knowledge of the Somongari Javanese community.

The implementation followed the six PBL stages proposed by Bender (2012). It integrated the four instructional stages of IKIM-PBL (stimulation, Western science discussion, indigenous knowledge exploration, and reflection). Students first organized project teams and planned their investigations, followed by classroom discussions and field observations in Somongari Village. They subsequently developed educational video artefacts, refined their products through additional data collection, revised the final storyline, and presented their completed projects.

Interview data indicated that students responded positively to the implementation of IKIM-PBL. Four major themes emerged from the interviews. First, students described the learning experience as engaging and different from conventional classroom instruction because they learned directly in natural and cultural settings. Second, students reported improved understanding of biodiversity through authentic observations and interactions with local community members. Third, learning in Somongari Village increased students' appreciation of local culture and indigenous knowledge while broadening their perspectives on biodiversity conservation. Finally, collaborative project activities promoted teamwork and communication through discussion, task sharing, and joint problem-solving, although several students reported minor challenges with time allocation and group coordination. Overall, these findings suggest that IKIM-PBL was successfully implemented and received positively by students as an authentic project-based learning experience.

Evaluate Phase

Descriptive Analysis

The evaluate phase examined whether the performance targets established during the analysis phase were achieved following the implementation of IKIM-PBL. Table 1 summarizes the distribution of students across the performance criteria for BK, BA, and TCS before and after the intervention. Overall, the implementation of IKIM-PBL resulted in substantial improvements in students' performance. The proportion of students classified in the low-performance category decreased for BK from 96.00% to 48.00%, for BA from 68.00% to 24.00%, and for TCS from 28.00% to 20.00%. Consequently, the predetermined performance targets established during the analysis phase were achieved for all three learning outcomes. In addition, the proportions of students in the high and sufficient performance categories increased across all variables after the implementation of IKIM-PBL.

Inferential Analysis

The normality of the difference scores (post-test minus pre-test) was first assessed using the Shapiro–Wilk test to determine the appropriate inferential statistical procedure. The results showed that the difference scores for biodiversity knowledge (BK) ($W = 0.869$, $p = 0.004$) and team communication skills (TCS) ($W = 0.879$, $p = 0.007$) were not normally distributed. In contrast, biodiversity awareness (BA) ($W = 0.964$, $p = 0.493$) satisfied the normality assumption. Accordingly, the Wilcoxon signed-rank test was applied to BK and TCS, whereas the paired-samples t-test was applied to BA. The results of the inferential statistical analyses are presented in Table 2.

Table 1

Summary of Criteria for the Number of Students with BL (BK and BA) and TCS during the Evaluate Phase

Criteria		BK		BA		TCS	
		Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)
High	Excellent	0.00	16.00	0.00	4.00	4.00	8.00
	Above average	0.00	24.00	16.00	24.00	12.00	28.00
Sufficient	Average	4.00	12.00	16.00	48.00	36.00	44.00
Low	Below average	16.00	24.00	60.00	20.00	44.00	20.00
	Failure	80.00	24.00	8.00	4.00	4.00	0.00

Table 2

Inferential Statistics for Biodiversity Knowledge, Biodiversity Awareness, and Team Communication Skills

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	Statistical test	Test statistic	p	Effect size
BK	9.84 ± 3.87	16.56 ± 4.78	Wilcoxon signed-rank	Z = -4.335	< 0.001	r = 0.87
BA	102.12 ± 12.82	113.04 ± 12.27	Paired-samples t-test	t(24) = -4.484	< 0.001	d = 0.90
TCS	82.60 ± 9.77	88.12 ± 11.17	Wilcoxon signed-rank	Z = -1.915	0.056	r = 0.38

The inferential analyses demonstrated that IKIM-PBL significantly improved students' BK and BA. BK showed a statistically significant increase after the implementation of IKIM-PBL ($Z = -4.335$, $p < 0.001$) with a large effect size ($r = 0.87$). Likewise, BA significantly increased from pre-test ($M = 102.12$, $SD = 12.82$) to post-test ($M = 113.04$, $SD = 12.27$), $t(24) = -4.484$, $p < 0.001$, with a large effect size (Cohen's $d = 0.90$). In contrast, although TCS showed a higher post-test score than the pre-test score, the improvement was not statistically significant ($Z = -1.915$, $p = 0.056$). Nevertheless, the observed effect size ($r = 0.38$) indicated a medium practical effect, suggesting that improvements in TCS may require a longer implementation period or repeated collaborative learning experiences. Overall, the findings indicate that IKIM-PBL effectively improved BK and BA, whereas improvements in TCS did not reach statistical significance despite a moderate practical effect.

DISCUSSION

This study addressed the three research questions proposed in the Introduction. First, the findings demonstrated that the IKIM-PBL module was successfully developed by integrating indigenous knowledge, Western science, and Project-Based Learning through the ADDIE instructional design model. Second, the module demonstrated high validity and practicality, as evidenced by expert validation, formative evaluations, and positive student perceptions during implementation. Third, the implementation of IKIM-PBL significantly improved students' BK and BA, whereas TCS showed a moderate practical improvement, though not statistically significant. Collectively, these findings indicate that IKIM-PBL is a promising instructional approach for supporting biodiversity education through authentic learning experiences.

The positive expert validation results and favorable student perceptions suggest that the instructional characteristics incorporated into IKIM-PBL contributed to its feasibility and practicality for classroom implementation. The module was designed with an attractive layout (Clark & Phillips, 2019), communicative language (Pakpahan & Saragih, 2022; Valois, 2022), update and integration of Western science (Cohen, 2010), presenting indigenous knowledge content (Gonçalves et al., 2021; Ishtiaq et al., 2013; Kosoe et al., 2020), constructivist learning activities (Jumaat et al., 2017; Olusegun, 2016; Palit, 2018), literacy-oriented tasks (Cook-Gumperz, 2006; Durant, 1994; Street, 2011), opportunities to develop 21st-century skills (Lee et al., 2015; Straub et al., 2017), and and character education (Agboola & Chen, 2012; Pala, 2011; Singh, 2019). These instructional characteristics are consistent with recommendations for contemporary instructional materials that emphasize active learning, meaningful communication, and authentic learning experiences. The positive responses from expert validation, one-to-one evaluation, small-group evaluation, field trials, and pilot testing further demonstrate that the module met both validity and practicality requirements prior to classroom implementation.

The significant improvements in BK and BA indicate that integrating IK with authentic PBL can effectively support biodiversity education. Biodiversity conservation has become a global educational priority through international initiatives such as the Sustainable Development Goals (SDGs) and the Aichi Biodiversity Targets, both of which emphasize the importance of biodiversity education in promoting environmental sustainability (Koulouri et al., 2022; Schneiderhan-Opel & Bogner, 2020; United Nations, 1992). Previous studies have also shown that learning experiences conducted in biodiversity-rich environments improve students' understanding of biodiversity and strengthen their engagement with environmental issues (Kamudu et al., 2022; Moss et al., 2014; Schneiderhan-Opel & Bogner, 2020; Wells et al., 2021). The present study extends these findings by demonstrating that authentic learning experiences combining classroom instruction with direct field exploration can simultaneously improve conceptual understanding and biodiversity awareness. Students learned not only through classroom discussions but also through direct observation, interviews, and authentic interactions with the Somongari Javanese community, thereby connecting scientific concepts to real-world biodiversity issues.

The integration of IK provided students with broader perspectives on biodiversity beyond scientific classification alone. IK represents accumulated local understanding of biodiversity that has developed through long-term interactions between communities and their surrounding environments (Adam et al., 2019; Gonçalves et al., 2021; Ishtiaq et al., 2013; Malekani, 2020; Selemani, 2020). This finding is consistent with Villarroel et al. (2025), who argued that integrating Indigenous educational methods into natural science education enables culturally meaningful and contextually relevant learning experiences through observation, experimentation, and authentic engagement with the local environment.

Through the IK of the Somongari Javanese community, students explored biodiversity at the genetic, species, and ecosystem levels (Benn, 2010; Swingland, 2013; WWF & WCEE, 1996), while simultaneously recognizing its cultural, ecological, social, economic, and conservation values (Saito, 2013). Rather than learning biodiversity solely as a biological concept, students experienced how biodiversity is closely intertwined with local traditions, livelihoods, and environmental stewardship. These authentic learning experiences enabled students to perceive biodiversity as a multidimensional concept encompassing conservation (Antongiovanni et al., 2022; Attum et al., 2022; Thorpert et al., 2022), ecological, (Cox & Rodway-Dyer, 2022; Recasens et al., 2022), cultural, (Alho, 2008; Gowdy, 1997), nutritional, (Costa et al., 2022; Gatti et al., 2022), and economic values (Anthony & Morrison-Saunders, 2023; Costa et al., 2022; Valck & Rolfe, 2022). This broader perspective may explain the significant improvement in biodiversity awareness observed after the implementation of IKIM-PBL, as students learned to appreciate biodiversity not only as a scientific concept but also as a valuable socio-cultural and environmental resource.

Although team communication skills did not improve significantly following the implementation of IKIM-PBL, the observed medium effect size suggests that the instructional intervention produced meaningful practical improvement. This finding is reasonable because PBL primarily provides opportunities for students to communicate, negotiate, exchange ideas, and solve authentic problems collaboratively throughout the learning process (Bender, 2012; Kokotsaki et al., 2016; Lou & Kim MacGregor, 2004; Sauter et al., 2022). Through collaborative projects, students are encouraged to organize their work, share responsibilities, discuss alternative solutions, and construct knowledge collectively, all of which are essential components of effective team communication.

The descriptive findings also showed improvements across the three dimensions of TCS, namely closed-loop communication (CLC), information exchange (IE), and listening activity (LA). CLC enables team members to confirm and clarify messages, thereby reducing misunderstandings and improving task efficiency (Bhangu et al., 2022; Diaz & Dawson, 2020; Hughes et al., 2020; Seferagić et al., 2021). Likewise, IE supports team cohesion and collaborative problem solving by encouraging members to share relevant knowledge and coordinate their activities effectively (Aubé et al., 2014; McLaren & Spink, 2018; Viitanen et al., 2011; Wang & Wang, 2011). LA are equally important because active listening facilitates accurate information transfer, minimizes communication errors, and promotes mutual understanding among team members (Benjamin & Kline, 2019; Itzchakov & Grau, 2022; Nakanishi et al., 2019).

Despite these positive tendencies, the improvement in TCS was not statistically significant. One possible explanation is that communication competence develops progressively through repeated collaborative experiences rather than a single instructional intervention. In the present study, IKIM-PBL was implemented over only eight learning sessions, which may have been insufficient for students to establish stable communication patterns within their groups. Previous studies have also reported that PBL may be constrained by limited instructional time and differences in student characteristics (Kusumawati, 2019). Furthermore, successful teamwork depends not only on instructional design but also on leadership, group dynamics, and mutual understanding among team members (Hussein, 2021; Steenhuis, 2019; Szydlo et al., 2020). Therefore, future implementations of IKIM-PBL may benefit from longer project durations, explicit communication training, structured role assignments, and collaborative reflection sessions to further strengthen students' team communication skills.

The findings of this study have important implications for biodiversity education. The successful integration of IK with Western science demonstrates that local cultural knowledge can serve as a meaningful context for learning modern biological concepts. Such an approach not only strengthens students' conceptual understanding and biodiversity awareness but also provides authentic opportunities for collaborative learning through PBL. Although improvements in TCS did not reach statistical significance, the observed positive trend suggests that integrating authentic field experiences with collaborative projects may support the gradual development of students' communication competencies. Consequently, IKIM-PBL may provide an alternative instructional approach for teachers seeking to implement contextual, culturally responsive, and project-based biodiversity learning while simultaneously promoting students' twenty-first-century skills.

This study has several limitations. First, the IKIM-PBL module was developed and implemented using the IK of the Somongari Javanese community within a single educational context. Although the module demonstrated high validity and practicality, its applicability to other cultural and educational settings requires further investigation. Future studies should adapt and evaluate the IKIM-PBL framework using indigenous knowledge from different regions to examine its transferability across diverse cultural and ecological contexts. Second, the instructional content focused on a limited range of IK related to biodiversity. Considering Indonesia's extraordinary cultural diversity and biological richness, future instructional modules should incorporate a broader range of indigenous knowledge and local wisdom contexts (Adinugraha, 2022). Indonesia possesses abundant cultural resources that can enrich science learning (Zubaidah & Arsih, 2021), including traditional performing arts such as Randai (Arsih et al., 2019), ethnobotanical knowledge of medicinal plants (Azis et al., 2020; Lestari et al., 2020; Silalahi & Nisyawati, 2018), and ethnobiological knowledge related to animals used in traditional medicine (Supiandi et al., 2023). Expanding the IKIM-PBL framework across diverse indigenous knowledge systems may strengthen biodiversity education while simultaneously supporting the preservation of Indonesia's rich biocultural heritage.

CONCLUSIONS

This study developed an Indigenous Knowledge-oriented Instructional Module integrated with Project-Based Learning (IKIM-PBL) using the ADDIE instructional design model. The developed module integrates indigenous knowledge, Western science, and Project-Based Learning through instructional characteristics that emphasize constructivist learning, authentic field experiences, literacy-oriented activities, 21st-century skills, and character education. Expert validation confirmed the module's high validity, while successive formative evaluations demonstrated its practicality for classroom implementation. These findings indicate that IKIM-PBL is a valid, practical, and feasible instructional resource for biodiversity education.

The implementation of IKIM-PBL significantly improved students' biodiversity knowledge (BK) and biodiversity awareness (BA). Although improvements in team communication skills (TCS) did not reach statistical significance, a moderate effect size suggests that the module has the potential to strengthen students' collaborative communication. These findings suggest that integrating indigenous knowledge with Project-Based Learning effectively supports biodiversity literacy while providing meaningful opportunities for collaborative learning that may enhance team communication skills. Beyond its contribution to biodiversity education, IKIM-PBL offers a culturally responsive instructional framework for integrating indigenous knowledge into science education and has the potential to support the Sustainable Development Goals related to quality education and biodiversity conservation. Future research should adapt and evaluate the IKIM-PBL framework across diverse indigenous knowledge contexts and biological topics to further extend its applicability and educational impact.

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AUTHORS' CONTRIBUTIONS STATEMENTS

Conceptualization: F.A.; Methodology: F.A., S.Z., and S.R.L.; Validation: S.Z. and S.R.L.; Formal analysis: F.A.; Investigation: F.A.; Visualization: F.A.; Writing – original draft: F.A.; Writing – review & editing: S.Z. and S.R.L.; Supervision: S.Z. and S.R.L.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Permission to conduct this study was obtained from the Principal of Bruderan Purworejo High School prior to data collection. The study was conducted as part of regular biology learning activities and posed no more than minimal risk to participants. The school informed parents or legal guardians about the field-based learning activities through an official notice, and students participated with their parents' permission. Participation in questionnaires, tests, observations, interviews, and project activities was voluntary. All participant data were anonymized, treated confidentially, and reported only in aggregate form. Verbal informed consent was obtained from community participants before interviews and documentation were conducted. Because this study was integrated into routine classroom instruction and involved minimal-risk educational activities, no separate institutional ethics committee approval was obtained.

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