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Enhancing Multidimensional Student Engagement through Project-based Experiment Learning: Integrating Indigenous Knowledge in Science Education

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ABSTRACT

Student engagement in science learning and laboratory practice is often less than optimal, especially in Indonesia's higher education context. Conventional learning models are based on the lecturer and have not accommodated the full multidimensional involvement of students. The current study developed and evaluated an innovative learning model, Project-based Experiment Learning (PBEL), through a herbal medicine project. The quasi-experimental research design with a pretest-posttest control group involved 175 students from three universities in Central Java—a valid and reliable questionnaire measured multidimensional engagement (behavioural, emotional, cognitive, and skills). Data analysis used ANCOVA to control for pretest scores. Findings confirmed that PBEL significantly promoted student engagement on all four dimensions compared to Project-based Learning (PjBL), with the most significant effects on emotional and skill engagement. The effectiveness of PBEL was consistent across the three institutes, suggesting validity across institutional contexts. The PBEL model enhances students' multidimensional engagement in local context-based science learning. The PBEL model is recommended for curriculum and pedagogy development in higher education, especially in preserving and utilizing indigenous knowledge as a meaningful learning resource.

Keywords: Project, Student Engagement, Indigenous Knowledge, Science, Higher Education

INTRODUCTION

Student engagement in education is presently understood as the physical presence of students in the lecture hall and includes a much broader and more complex dimension. In their conceptual framework, Fredricks et al., (2004) identified engagement as a multidimensional construct that includes behavioural, emotional, and cognitive engagement. Alongside these three dimensions, in the context of science higher education that emphasizes practice, skill engagement is also an important aspect, which is seen in how students synthesize knowledge through experimental activities or field projects (Bryson, 2016; Cook-Sather et al., 2014; Verwoord, 2016). Kuh, (2009) suggests that student engagement is directly proportional to the quality of the learning experience and is the main prerequisite for forming meaningful learning and mastery of competencies.

However, although the importance of student engagement has been widely recognized, the reality is that engagement is still a serious problem in higher education, especially in science learning and laboratory practices. Hrynowski, (2024) survey of more than 4,000 children and young adults aged 12 to 27 in the United States (including more than 2,300 K-12 students) found that between 25% and 54% did not experience engaging learning experiences at school, such as feeling that what they were learning was important or interesting. Less than half of students stated that their schoolwork provided a positive challenge (49%) or was to the best of their ability (46%), illustrating low levels of engagement in the learning process. Oliver et al., (2021) survey likewise reported that students' engagement in science tends to decline in higher education, resulting in low concept retention and interest in science. Cook-Sather et al., (2014) revealed that lecturer-centered learning approaches, lack of independent investigation opportunities, and lack of material relevance to real life or local culture often cause low engagement. Student engagement is critical to support meaningful learning, long-term retention, and mastery of 21st-century skills such as critical thinking, problem-solving, and collaboration (Fredricks et al., 2004). During laboratory practice (Engaging, 2011) reported that activities often only emphasize mechanistic procedures without fostering curiosity and inquiry, thus failing to optimize mastery of scientific concepts and skills. The highlighted condition indicates the need for a learning model that combines projects, experiments, and real-life contexts or indigenous knowledge to enhance multidimensional student engagement to be more effective in preparing adaptive and competent graduates (Aker & Ellis, 2019; Soriano-Sánchez, 2025).

The disparity in learning practices in higher education is still evident, where conventional approaches such as lecture-based methods and standard practicum still dominate the learning process, especially in science courses (Mebert et al., 2020; Soriano-Sánchez, 2025). The lecture-based approach has not fully facilitated all dimensions of student engagement, whether behavioural, emotional, cognitive, or practical skills (Cook-Sather et al., 2014; Verwoord, 2016). In their study on physics learning, Maison et al. (2020) reported that traditional methods that emphasize lectures tend to produce lower concept understanding improvement than interactive approaches. Similarly, in their literature review, Sakeef et al. (2025) asserted that teacher-centred learning often suppresses students' curiosity, creativity, and collaboration opportunities, thus limiting the development of higher-order thinking skills. Moreover, practicums conducted procedurally without encouraging independent investigation often fail to generate students' emotional and cognitive engagement (Godec et al., 2018). The matter suggests that there is still a significant gap between conventional learning practices and the need to create learning experiences that support multidimensional students' engagement.

Innovative approaches to science learning through integrating projects and experiments provide strategic opportunities to enhance student engagement more comprehensively (Harris et al., 2015; Juuti et al., 2021; Miller et al., 2021). Several studies have proved that project-based learning effectively enhances students' cognitive engagement, curiosity, and collaboration skills (He et al., 2023; Krajcik & Blumenfeld, 2020). Similarly, experiment-based approaches have facilitated practical skills, problem-solving, and more profound concept mastery (Chen et al., 2019; Rohimat, 2022). However, the systematic integration of the two approaches simultaneously promoting project activities and experiments in one integrated learning model is relatively under-researched (Moitra & Madan, 2025; Parmin et al., 2017). Moreover, when it comes to the utilization of Indigenous knowledge context that can enhance the relevance of the material to student's real life and enrich the learning experience from the perspective of local culture, is still remarkably limited (Ayuttacorn, 2024; Latai-Niusulu et al., 2024; Michie et al., 2023).

Indonesia has abundant cultural wealth and indigenous knowledge, covering various aspects of life, from traditional health practices and food technology to environmental management (Food and Agriculture Organization, 2020). One example is the tradition of making herbal medicine, which is evidence-based knowledge about using medicinal plants to maintain health (Dabaghian et al., 2023). Unfortunately, this great potential has not been optimally utilized as a learning resource in science education in higher education. However, with its biological and cultural diversity, Indonesia can be likened to a vibrant *live laboratory* for learning local wisdom-based science (Food and Agriculture Organization, 2020). The aforementioned approach increases the relevance of learning materials to the context of students' lives and fosters a sense of belonging and pride in one's cultural heritage (Martín, 2015). Furthermore, integrating indigenous knowledge into science learning can broaden students' perspectives in understanding scientific concepts holistically while supporting the development of a scientific identity rooted in local culture but with a global outlook (Rahmawaty, 2020).

The research introduces a Project-Based Experiment Learning (PBEL) model designed to integrate project activities, scientific experiments, and the context of indigenous knowledge in an integrated conceptual framework. The PBEL model invites students to not only engage in a project to make herbal medicine a representation of local cultural wealth but also carry out a series of scientific experiments to test the physical-chemical and organoleptic properties of the products produced. The research offers a new dimension in science learning because it integrates ethnoscience contexts relevant to students' lives while developing scientific thinking skills through structured experiments. The PBEL model not only enriches the study of science pedagogy in higher education but also makes a scientific contribution to filling the literature gap related to the systematic integration of projects, experiments, and Indigenous knowledge as a learning strategy that supports the formation of graduates who are adaptive, creative, and rooted in the culture of their nation.

Research Questions. RQ1: How does implementing the Project-Based Experiment Learning (PBEL) model compare to the conventional Project-Based Learning (PjBL) model in enhancing students' multidimensional engagement after controlling for prior academic achievement across three universities in Central Java?; RQ2: To what extent does the PBEL model yield a statistically significant improvement over the PJBL model on students' overall engagement scores after adjusting for pre-existing differences, and are these effects consistent across different university contexts?; RQ3: Does integrating indigenous knowledge through the PBEL approach particularly strengthen specific dimensions of engagement more than the PJBL approach when controlling for initial competency levels?

LITERATURE REVIEW

Conceptualizing Student Engagement

Student engagement is a central concept in higher education studies that refers to the extent to which students are physically, emotionally, and mentally involved in the learning process. Fredricks et al. (2004) suggested multidimensional student engagement, including behavioural, emotional, and cognitive. Behavioural engagement is reflected in students' active participation in learning activities, such as attending, taking notes, discussing, and doing assignments (Sinatra et al., 2015). Meanwhile, emotional engagement refers to students' affective responses to the learning process, including a sense of interest, enthusiasm, and a positive attitude towards the material and lecturer (Fredricks et al., 2004). Meanwhile, cognitive engagement shows the level of mental effort of students in understanding, analyzing, and integrating new knowledge with their cognitive structures (Stolk et al., 2021). Kuh (2009) further expanded this understanding by emphasizing that engagement can also include practical skills, which relate to the application of knowledge through authentic hands-on activities. Recent studies have confirmed that high levels of student engagement positively correlate with learning outcomes, including deeper concept understanding, critical thinking skills, and long-term retention (Mattanah et al., 2024; Sinatra et al., 2015; W. Zhang et al., 2025). Therefore, multidimensional student engagement is an important indicator of the quality of the learning process and a fundamental prerequisite for a meaningful learning experience.

Project-Based Learning (PjBL) in Science Education

Project-Based Learning (PjBL) is a pedagogical approach that emphasizes learning through the completion of real projects so that students are actively involved in exploring, designing, and solving authentic problems (Mebert et al., 2020; Zen et al., 2022). Regarding science education, PjBL has been widely researched and shown its effectiveness in improving learning outcomes and student engagement. Dai et al. (2024) and Torrijo et al. (2021) reported that PjBL encourages a deeper understanding of concepts because students memorise material and construct knowledge through hands-on experience. Furthermore, research by Mebert et al. (2020) confirmed that PjBL enhances curiosity, creativity, collaboration skills, and the ability to solve complex problems. However, despite having several advantages, applying PjBL also has limitations. A study by Blumenfeld et al. (1994) highlighted that without careful design, students tend to focus more on the final product than the scientific process, which should be the primary goal so that conceptual understanding can be less than optimal. Moreover, PjBL requires the support of time, resources, and high facilitation competence from lecturers in order to run effectively. Therefore, although PjBL is proven to enhance student engagement and learning outcomes in science education, the approach requires careful instructional design so that cognitive, affective, and practical skills objectives can be balanced.

Experiment-Based Learning Approaches

The experiment-based learning approach is a strategy in science education that emphasizes students' direct experience through empirical investigation and systematic observation of natural phenomena (Dimopoulou & Gasparatou, 2023). Experimental activities enhance students' ability to develop science process skills such as formulating hypotheses, designing procedures, collecting data, analyzing results, and drawing conclusions based on evidence (Develaki, 2019). Ateş (2024) asserts that experiment-based learning significantly improves students' critical thinking skills because they are encouraged to evaluate data, solve problems, and interpret findings reflectively. Furthermore, students' involvement in experiments strengthens concept mastery and increases engagement at the cognitive, emotional, and practical skill levels (Ürek, 2025). However, to maximize the potential of the approach, experiments need to be designed not only procedurally but also to provide space for inquiry and reflective discussion so that they can hone students' scientific abilities and curiosity.

Integrating Indigenous Knowledge into Science Education

Integrating indigenous knowledge into science learning is increasingly recognized as an approach to enhancing education's relevance, meaningfulness, and cultural sensitivity (Ojalehto et al., 2017). Indigenous knowledge, such as traditional medicine practices (Harfouche et al., 2021), food technology (Linger, 2017) or sustainable agriculture systems (Harfouche et al., 2021), contains scientific principles that can be used as authentic contexts for understanding modern science concepts (Food and Agriculture Organization, 2020). Learning that links science to indigenous knowledge not only strengthens students' sense of belonging and pride in their cultural heritage but has also been proven to enhance engagement and facilitate a more contextualized understanding of concepts (Martín, 2015). However, the literature highlights that systematic integration of Indigenous knowledge with modern science learning models, such as project-based or experiment-based learning, is still relatively limited (Harfouche et al., 2021; Linger, 2017; Ojalehto et al., 2017; Templeman et al., 2018). The disparity indicates the need for more research that develops pedagogical frameworks to bridge modern science with indigenous knowledge so that science education is universal, abstract, and relevant to students' real lives in a socio-cultural context.

Synthesis and Identification of Research Gaps

A previous literature review indicates that project-based learning enhances students' concept understanding, collaboration skills and curiosity. In contrast, experiment-based learning contributes significantly to developing science process skills and critical thinking. However, integrating indigenous knowledge in science learning has been recognized to enrich the learning context and strengthen cultural relevance, although its implementation in a formal pedagogical framework is still limited. Nonetheless, the literature review highlighted a gap in that few studies have systematically combined project approaches, experiments and indigenous knowledge contexts into one integrated learning model. Moreover, most previous studies focused on student engagement in one or two dimensions, such as cognitive or behavioural aspects, without measuring multidimensional engagement that simultaneously includes behavioural, emotional, cognitive, and skills. Considering this context, research that develops and tests the PBEL model addresses this gap. The PBEL model is specifically designed by combining herbal medicine-making projects rooted in Indigenous knowledge, scientific experiments to test product characteristics, and reflection and discussion activities to strengthen conceptual understanding. The conceptual framework of PBEL instructional design is presented in Figure 1.

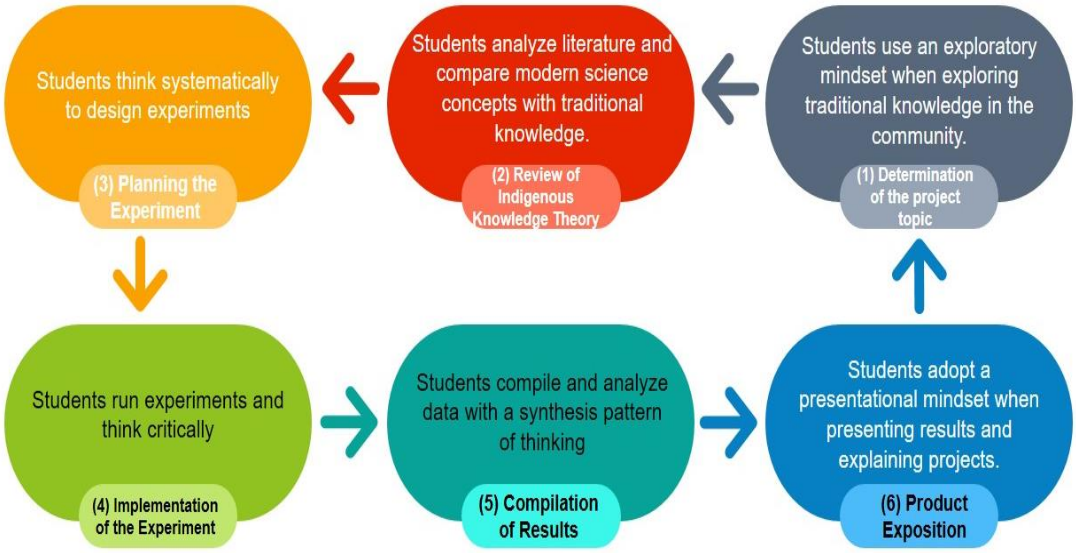

Figure 1. The Instructional Design Conceptual Framework of PBEL.

RESEARCH METHODOLOGY

The research used a quasi-experimental design with a pretest-posttest non-equivalent control group design because it considered field conditions that did not allow complete random sample assignment but still allowed comparison between groups by measuring initial conditions (pretest) and final results (posttest). The experimental group received treatment through the Project-Based Experiment Learning (PBEL) model, while the control group followed learning with the conventional Project-Based Learning (PjBL) model. To analyze the effectiveness of the PBEL model in increasing multidimensional student engagement, the Analysis of Covariance (ANCOVA) test was used with the pretest score as a covariate. ANCOVA makes it possible to control for initial differences between groups and evaluate the effect of treatment more accurately. The quasi-experimental design also provides a strong basis for testing the contribution of the PBEL model in increasing student engagement in the behavioural, emotional, cognitive, and skill dimensions in the context of indigenous knowledge-based science learning.

Participants

The present study involved a total of 175 students from three universities in Central Java which are Universitas Sebelas Maret (UNS), Universitas Muhammadiyah Surakarta (UMS), and Universitas Veteran Bangun Nusantara (UNIVET). The study population amounted to around 450 students of the Elementary School Teacher Education Study Program at the three universities who were taking courses related to science learning in the even semester of the 2024/2025 academic year. The sample was determined using a purposive sampling technique by considering the willingness of the study program, the readiness of the class, and the uniformity of the courses being taken to obtain classes that can be given different treatments but still commensurate. From the selection results, students were then divided into two groups that is, the experimental group consisting of 90 students who received treatment with the PBEL model, and the control group consisting of 85 students who received learning using Project-Based Learning (PjBL). The difference in treatment lies in integrating scientific experiments and the context of indigenous knowledge in the PBEL group, while the PJBL group only carries out product manufacturing projects without systematic experimental stages that emphasize testing of physical-chemical and organoleptic properties. The distribution of student demographic characteristics in both groups was relatively balanced in terms of age, gender, institutional origin, semester of study, previous science learning experience, and regional origin, as presented in Table 1.

Table 1. Distribution and Comparison of Descriptive Characteristics of Students in The Experimental and Control Groups.

Demographics	Sub Demographics	Group			
		Experiment (PBEL)		Control (PjBL)	
		N	%	N	%
Age	20^{th} Years	28	31%	26	31%
	21^{th} Years	42	47%	39	46%
	22^{th} Years	20	22%	20	23%
Gender	Male	38	42%	37	44%
	Female	52	58%	48	56%
Institution	Universitas Sebelas Maret (UNS)	30	33%	28	33%
	Universitas Muhammadiyah Surakarta (UMS)	30	33%	28	33%
	Universitas Veteran Bangun Nusantara (UNIVET)	30	33%	29	34%
Semester of Study	4th Semester	53	59%	50	59%
	6th Semester	37	41%	35	41%
Previous science learning experience	Basic Science Practicum.	60	67%	58	68%
	Science Learning Methodology	30	33%	27	32%
Regional origin	City	48	53%	45	53%
	Village	42	47%	40	47%

Procedures

The research, including instrument preparation, pretest implementation, treatment application to each group, and posttest data collection, took place between February and June 2025. Every learning procedure was carried out in a classroom and laboratory setting, with sixteen meetings, allowing researchers to evaluate students' multidimensional involvement optimally. Each learning stage in this study lasted four weeks, with the distribution of science materials designed to be integrated according to PBEL. Learning with a four-week time allocation (Table 2) allows students to be actively involved at each stage, both behaviorally, emotionally, cognitively and in developing practical skills.

Table 2. Schedule and Details of PBEL Learning Activities on Herbal Medicine Making Project.

Time	Science Materials	Example Activity/Focus
Week 1	Biology: Plant morphology, anatomy & benefits (Botany, Physiology)	- Identifying turmeric rhizome & tamarind fruit (external and internal structure) - Discussion of health benefits (curcumin & organic acids) - Familiarity with family medicinal plants & phytopharmaceuticals
Week 2	Chemistry: Extraction of active substances & pH (Solutions, pH, Active compounds)	- Boiling turmeric & tamarind, observing color - Measuring pH of herbal medicine solution - Simple test of color stability under acid/base conditions
Week 3	Physics: Heating, conduction & filtration (Heat, Separation)	- Measuring temperature during boiling - Discussion of heat conduction in panic

		- Filtering dregs, discussion of filtration principles
Week 4	Technology integration & application (Biology, Chemistry, Physics & Technology/Entrepreneurship)	- Designing simple labels (composition & benefits) - Discussion on hygiene & business potential of herbal medicine - Presentation of project results & product demo

The PBEL learning model is designed through six main stages that are integrated. First, the project topic determination stage directs students to choose a herbal medicine-making project based on local potential, health relevance, and group interest. Second, the review of indigenous knowledge theory, in which students identify and examine cultural values related to the tradition of making and consuming herbal medicine through literature, light interviews, or observations in the surrounding environment. Third, the experimental planning stage focuses students on preparing coherent experimental procedures, including identifying tools, materials, and estimated implementation time. Fourth, the experiment implementation stage, where students in groups make herbal medicine according to the design, document the process and pay attention to safety and hygiene principles. Fifth is the results compilation stage, which involves preparing a group report containing empirical data (e.g. taste, colour, pH), integrated analysis of biology-chemistry-physics concepts, and visual documentation of the product. Finally, the product exhibition stage provides space for students to present the project results in the form of posters or leaflets and participate in a mini exhibition in class to promote their products. An example of learning implementation using the PBEL model is presented in Table 3. In contrast to conventional PjBL, which generally stops at the final product without explicit integration of scientific processes and local wisdom contexts, PBEL systematically combines elements of projects, scientific experiments, and cultural meanings in one learning flow.

Table 3. Example of Implementation in Week 1 Material Morphology, Anatomy and Benefits of Plants.

Learning Stages	**Learning Objectives**	**Learning Task Guide**
Determination of project topic	Students are able to determine the topic of herbal medicine project based on local potential, health relevance, and group interest.	- Students discuss in groups to choose a herbal medicine project. - Develop reasons for selection based on local potential and health benefits.
Review of indigenous knowledge theory	Students are able to identify and examine local wisdom values related to the tradition of making and consuming herbal medicine.	- Students browse literature/articles, conduct light interviews or observations about the tradition of drinking herbal medicine around them. - Document local wisdom values (e.g. family traditions, traditional ceremonies, herbal medicine market culture).
Experiment planning	Students are able to design experimental steps for making herbal medicine coherently and prepare the needs of tools and materials.	- Students design experimental procedures for making herbal medicine (flowchart, table of tools & materials). - Arrange the estimated time of implementation.
Experiment implementation	Students are able to carry out herbal medicine making experiments according to the procedures that have been designed by paying attention to safety and hygiene.	- Students in groups make herbal medicine according to the design, while documenting the process.
Compilation of results	Students are able to compile reports that contain experimental results, integrated science analysis, and documentation of processes and products.	- Students compile result data (e.g. taste, color, pH), science analysis (biology-chemistry-physics), and process and product photos. - Make a final group report.
Product exhibition	Students are able to present project results in the form of herbal medicine product exhibitions, including explanatory posters/leaflets.	- Students prepare posters/leaflets containing product information. - Participate in a mini exhibition in class to present the project results and offer herbal medicine products.

Measurements in the study were carried out two times, namely before treatment *(pretest)* and after treatment *(posttest)*, to obtain a comprehensive picture of changes in student involvement due to the application of PBEL and PjBL models. The instrument used is a multidimensional-based student involvement questionnaire, which is designed to measure four domains of involvement at once: behavioural, emotional, cognitive, and skill involvement. The questionnaire was administered to all students at the beginning of the study to map the initial condition of engagement (pretest), then re-administered after the entire learning series was completed (posttest) to assess the impact of treatment. The pre-post measurement design was controlled through analysis of covariance to ensure that the evaluation of the effect of the PBEL model on student engagement was carried out objectively. The research procedure design is presented in Figure 2.

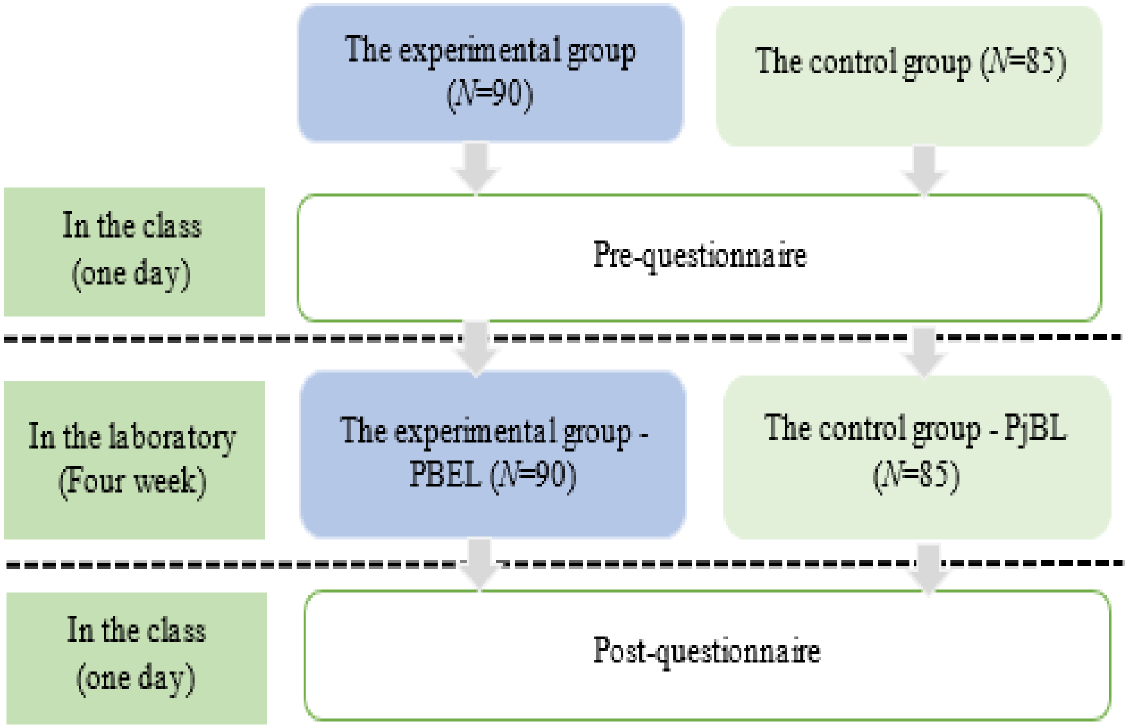

Figure 2. PBEL Instructional Design Research and Assessing Procedure.

To ensure the internal validity of the research, all experimental and control groups were given the same syllabus so that the subject matter, learning outcomes, and meeting time were of equal standard. The only difference was the learning model applied. In addition, to control for the possible influence of differences in students' initial abilities on multidimensional engagement, pretest scores were used as covariates in study data analysis through the ANCOVA test.

Instrument

The main instrument used in this study is a multidimensional student engagement questionnaire, which was developed by adapting the conceptual framework of Fredricks et al. (2004) regarding student engagement. The questionnaire was designed to measure four dimensions of student engagement, which are behavioural, emotional, cognitive, and skill engagement, with items developed based on a review of current literature on engagement in the context of higher education. Each dimension is measured through a series of statements that are responded to using a five-point Likert scale, from strongly disagree to agree strongly. The student engagement questionnaire used in this study was designed to measure the four dimensions of engagement. The student engagement questionnaire used in this study consists of a total of 25 items, which are distributed across the four dimensions of engagement. The behavioural engagement dimension is measured through 6 items that capture the extent to which students actively attend, take notes, ask questions, and engage in class discussions. The emotional engagement dimension is also measured by 6 items that assess students' enthusiasm, interest, comfort, and positive attitude towards the learning process. Meanwhile, another 6 items describe cognitive engagement, including students' efforts in understanding concepts, linking new knowledge with previous knowledge, and analytical thinking skills. The skill engagement dimension is measured by 7 items, which specifically assess students' participation in practical activities, experiments, and application of knowledge to real contexts.

The validity of the student engagement questionnaire was tested through two complementary approaches. First, content validity was ensured by requesting assessments from three experts, consisting of two science education expert lecturers and one psychometrician, who independently examined the relevance, clarity of the phrasing, and appropriateness of each item to the dimensions of behavioural, emotional, cognitive, and skill engagement. Each expert provided an assessment score on a scale of 1-4 for item suitability. The results were analyzed using the Content Validity Index (CVI) (Lawshe, 1975), which showed I-CVI (item-level CVI) values ranging from .83 to 1.00, with S-CVI/Ave (scale-level average) reaching .92, indicating that all items were considered very feasible and relevant to measure the intended construct. Second, construct validity was tested through exploratory factor analysis (EFA) on pilot test data involving 120 students. The analysis results showed a Kaiser-Meyer-Olkin (KMO) value = .861, which far exceeds the minimum threshold of 0.60 (Field, 2024), and the Bartlett's Test of Sphericity results showed $\chi^2(300) = 2156.43; p < .001$ which means that the correlation matrix between items is suitable for further analysis. The extraction process using principal component analysis and varimax rotation successfully identified four main factors consistent with the theoretical constructs of Fredricks et al. (2004), with item factor loadings ranging from 0.612 to 0.843 on each factor. The student engagement questionnaire has also been tested for internal reliability to ensure consistency between items in each dimension and the overall student engagement scale. The total alpha value for the whole questionnaire reached 0.89, indicating high internal consistency. Meanwhile, the reliability coefficients on each dimension ranged from 0.82 to 0.87, namely 0.84 for behavioural engagement, 0.82 for emotional engagement, 0.85 for cognitive engagement, and 0.87 for skill engagement.

Examples of statements of opinion items on each engagement dimension. Concerning the behavioural engagement dimension, one of the items reads, "*I am actively involved in project discussions*", which aims to capture the intensity of student participation in class and group activities. The emotional engagement dimension is measured, among others, by the item "*I feel enthusiastic about studying the traditional herbal medicine project*, " reflecting students' sense of pleasure and interest in the material being studied. Regarding the cognitive engagement dimension, one example item is "*I connect new information with the knowledge I already have*, " indicating the deep integration of concepts. Regarding the skill engagement dimension, there are items such as "*I believe I can perform scientific procedures in making herbal medicine*" and assessing students' confidence in applying practical science skills.

Data Analysis

The data analyzed in the study included pretest and posttest scores from the multidimensional student engagement questionnaire, which included behavioural, emotional, cognitive, and skill dimensions. Antecedent to the primary test using ANCOVA, a series of assumption tests were conducted to ensure the validity of the application of the analysis. The normality test of score distribution was conducted using Shapiro-Wilk and Kolmogorov-Smirnov ($p > .05$). Furthermore, the homogeneity of variance between groups was examined through Levene's Test, with results of $p > .05$ on all four dimensions of engagement, indicating that the variance between groups is relatively homogeneous. The linearity test between pretest and posttest scores also showed a significant linear relationship, strengthening the feasibility of using ANCOVA. To summarize, the assumption of homogeneity of regression slopes was tested to ensure no significant interaction between the covariate (pretest) and treatment (type of learning model) so that the slope of the regression line can be considered the same in both groups.

The ANCOVA technique was used to test the difference in multidimensional engagement posttest scores between the groups following the PBEL model and those following the PjBL model, controlling for pretest scores as covariates. The statistical significance criterion was set at $\alpha = 0.05$ level, which means the results are considered statistically significant if the *p-value* is below this limit. Alongside identifying the significance of differences in multidimensional engagement posttest scores between groups, this study also calculated the effect size using the partial eta squared (η^2) indicator. The use of effect size is intended to provide an overview of the magnitude of the contribution of the PBEL learning model to increasing student engagement compared to conventional PjBL.

RESEARCH RESULTS

Comparative Effects on Multidimensional Engagement (RQ1)

The descriptive statistical analysis found that the pretest mean student engagement scores were relatively similar between the groups learning using the PBEL model and those using PjBL (see Table 4). However, at the posttest stage, there was a higher increase in the PBEL group across all dimensions of engagement. Overall, the posttreatment mean total multidimensional engagement was recorded at 4.38 (SD = .41) for PBEL, higher than 4.01 (SD = .46) for PJBL. The descriptive findings indicate that implementing the PBEL model tends to be more effective in increasing student engagement than the PjBL model.

Table 4. Descriptive Statistics of Pretest & Posttest.

Model	N	Behavioral Engagement	Emotional Engagement	Cognitive Engagement	Skills Engagement	Total Engagement
		Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
Pretest						
PBEL	90	3.12 (.55)	3.08 (.50)	3.15 (.53)	3.05 (.58)	3.10 (.54)
PjBL	85	3.10 (.58)	3.05 (.52)	3.12 (.55)	3.02 (.57)	3.07 (.55)
Posttest						
PBEL	90	4.25 (.45)	4.35 (.42)	4.40 (.40)	4.50 (.38)	4.38 (.41)
PjBL	85	3.90 (.50)	4.00 (.47)	4.05 (.45)	4.10 (.43)	4.01 (.46)

The assumption test for further analysis revealed that the data met the parametric requirements. Based on the residual normality test with Shapiro-Wilk, the p-values were all greater than .05 for each dimension of student engagement, that is, behavioural engagement (p = .274), emotional engagement (p = .318), cognitive engagement (p = .226), and skills engagement (p = .193). Furthermore, the homogeneity of variance test using Levene's test also verified that the variance between groups was homogeneous($p_{\text{behavioural engagement}}$ = .482; $p_{\text{emotional engagement}}$ = .529; $p_{\text{cognitive engagement}}$ = .465; and $p_{\text{skills engagement}}$ = .371). Moreover, the interaction analysis between the pretest score and treatment group (PBEL vs PjBL) on each engagement dimension resulted in insignificant *p-value*, which is behavioural engagement (p = .423), emotional engagement (p = .387), cognitive engagement (p = .455), and skills engagement (p = .498). The above-mentioned indicates that the assumption of homogeneity of regression slopes is met. Accordingly, the overall assumption test results support the feasibility of using ANCOVA to test the effectiveness of PBEL versus PjBL models on student engagement.

The ANCOVA results controlling for pretest scores found a significant difference between PBEL and PjBL groups on the posttest scores of students' multidimensional engagement (See Table 5). In the behavioural engagement dimension, the value of $F_{(1,92)}$ = 6.72, p = .012, with a medium effect contribution indicated by η^2 = .067. The results were also significant for emotional engagement with $F_{(1,92)}$ = 8.45, p = .004, and η^2 = .084, indicating a relatively larger effect contribution. Similarly, there was a significant difference in cognitive engagement between the groups with $F_{(1,92)}$ = 9.70, p = .003, and η^2 = .095, indicating a moderate effect. Meanwhile, on skills engagement, the analysis yielded $F_{(1,92)}$ = 5.22, p = .025, with η^2 = .053. The ANCOVA findings indicated that implementing the PBEL model was significantly more effective than PjBL in improving student engagement on all four dimensions, even after controlling for the covariate variable of the pretest score. The magnitude of the partial η^2 value in each dimension also indicates a meaningful, practical effect of PBEL implementation.

Table 5. ANCOVA results comparing PBEL and PJBL on posttest engagement scores, controlling for pretest scores.

Dependent Variable	Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Behavioral Engagement	Group	12.34	1	12.34	6.72	.012	.067
	Error	169.00	92	1.84			
	Total	181.34	93				
Emotional Engagement	Group	15.87	1	15.87	8.45	.004	.084
	Error	172.80	92	1.88			
	Total	188.67	93				
Cognitive Engagement	Group	18.92	1	18.92	9.70	.003	.095
	Error	179.45	92	1.95			
	Total	198.37	93				
Skills Engagement	Group	10.45	1	10.45	5.22	.025	.053
	Error	184.02	92	2.00			
	Total	194.47	93				

Overall Engagement Scores and Contextual Consistency (RQ2)

The results of the descriptive analysis of the overall multidimensional engagement scores highlighted a consistent pattern across institutional contexts (see Table 6). The consistency of the pattern across the three university contexts reinforces the finding that the PBEL model tends to be more effective in increasing overall student engagement than the PjBL model, regardless of institutional variation. The findings of the descriptive analysis support the interpretation that the effectiveness of PBEL is stable across contexts, which provides an important basis for generalizing the model's applicability to higher education settings with similar characteristics.

Table 6. Descriptive Statistics of Overall Engagement.

Group	University	N	Pretest Mean (*SD*)	Posttest Mean (*SD*)
The experimental group - PBEL	UNS	30	3.10 (.52)	4.40 (.38)
The experimental group – PBEL	UMS	30	3.12 (.54)	4.35 (.40)
The experimental group – PBEL	UNIVET	30	3.08 (.56)	4.38 (.42)
The control group – PjBL	UNS	28	3.09 (.51)	4.00 (.43)
The control group – PjBL	UMS	28	3.13 (.53)	4.05 (.44)
The control group – PjBL	UNIVET	29	3.07 (.55)	3.97 (.45)

The two-way ANCOVA analysis controlling for pretest scores found a significant main effect of the learning model on students' multidimensional engagement scores on the posttest (see Table 7). The PBEL model significantly resulted in higher engagement scores than PjBL, with $F_{(1, 90)}$ = 15.32, p = .0002, and a substantial effect contribution indicated by partial η^2 = .142. Inversely, no significant main effect of the university factor on engagement scores was found ($F_{(2, 90)}$ = .64, *p* = .529, η^2 = .014), indicating that student engagement scores were relatively uniform across the three institutional contexts.

Table 7. Two-way ANCOVA Results on Posttest Overall Engagement.

Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Models	22.65	1	22.65	15.32	0.0002	0.142
University	1.87	2	0.94	.64	0.529	0.014
Models × University	1.15	2	0.58	.39	0.678	0.009
Covariate	12.45	1	12.45	8.42	0.0046	0.085
Error	136.23	90	1.51			
Total	174.35	96				

The interaction between the learning model and university was also not significant($F_{(2,90)}$ = .39, *p* = .678, η^2= .009), indicating that the superiority of the PBEL model over PjBL was consistent across the universities studied. The pretest score covariate contributed significantly to the model($F_{(1,90)}$ = 8.42, *p* = .0046, η^2= .085), confirming the importance of controlling for initial differences in engagement ability. The results of the two-way ANCOVA analysis strengthened the evidence that PBEL implementation was effective in enhancing multidimensional students' engagement in general, without being influenced by institutional context, thus supporting the generalizability of the results to similar higher education settings.

Analysis of estimated marginal means (EMMs) based on the results of the two-way ANCOVA, which combined data from the three universities and controlled for pretest scores, proved that students who participated in the PBEL model had higher multidimensional engagement scores compared to students who participated in the PjBL model. The EMM value for the PBEL group was recorded as 4.38 (*SE* = .08; 95% CI [4.22, 4.54]), while that for the PjBL group was 4.01 (*SE* = .08; 95% CI [3.85, 4.17]). The non-overlapping confidence intervals substantially support the conclusion of a consistent difference, emphasizing the superiority of PBEL in increasing overall student engagement. The EMM findings indicated that PBEL implementation had a greater positive impact on students' multidimensional engagement than PjBL, with a good estimation precision as indicated by the relatively small standard error values.

Specific Engagement Dimensions and Indigenous Knowledge Integration (RQ3)

Descriptive analysis of each dimension of student engagement showed a consistent pattern of enhancement in the PBEL group compared to PjBL, especially after integrating indigenous knowledge into learning activities (see Table 8). Descriptive findings indicate that the integration of Indigenous knowledge in PBEL not only strengthens the cognitive dimension but specifically has a more prominent impact on students' emotional engagement and skills. The above-mentioned indicates the good potential of Indigenous knowledge-based approaches in facilitating a more holistic and meaningful learning experience in the context of higher education.

The results of assumption testing for each dimension of student involvement showed that the data met the requirements of ANCOVA parametric analysis. The residual normality test using Shapiro-Wilk revealed that the residuals in all dimensions were normally distributed($p_{\text{behavioral involvement}}$ = .262; $p_{\text{emotional involvement}}$ = .318; $p_{\text{cognitive involvement}}$ = .243; and $p_{\text{skill involvement}}$ = .198). The homogeneity of variance test with Levene's test also revealed that the variance between groups was homogeneous on all dimensions, respectively, with $p_{\text{behavioral engagement}}$ = .473, $p_{\text{emotional engagement}}$ = .506, $p_{\text{cognitive engagement}}$ = .445, and $p_{\text{skill engagement}}$ = .379. Moreover, the assumption of homogeneity of regression slopes was also met, indicated by the insignificance of the interaction between pretest and group scores on all dimensions, with $p_{\text{behavioral engagement}}$ = .412; $p_{\text{emotional engagement}}$ = .387; $p_{\text{cognitive engagement}}$ = .455; and $p_{\text{skill engagement}}$ = .498. The finding indicates that the data meets the assumptions of residual normality, homogeneity of variance, and similarity of the slope of the regression line so that the use of ANCOVA on each dimension of involvement can be carried out.

Table 8. Descriptive Statistics for Each Engagement Dimension by Group.

Dimension Engagement	Group	*N*	Pretest Mean (*SD*)	Posttest Mean (*SD*)
Behavioral	The experimental group - PBEL	90	3.12 (.55)	4.25 (.45)
	The control group - PjBL	85	3.10 (.58)	3.90 (.50)
Emotional	The experimental group - PBEL	90	3.08 (.50)	4.35 (.42)
	The control group - PjBL	85	3.05 (.52)	4.00 (.47)
Cognitive	The experimental group - PBEL	90	3.15 (.53)	4.40 (.40)
	The control group - PjBL	85	3.12 (.55)	4.05 (.45)
Skills	The experimental group - PBEL	90	3.05 (.58)	4.50 (.38)
	The control group - PjBL	85	3.02 (.57)	4.10 (.43)

The ANCOVA results found significant differences between PBEL and PjBL groups on all four dimensions of student engagement (see Table 9). Regarding the behavioral engagement dimension, $F_{(1,91)} = 6.72$, $p = .012$, $\eta^2 = .069$ indicating a moderate effect contribution. Concerning emotional engagement, the results were also significant with $F_{(1,91)} = 8.45$, $p = .004$, and $\eta^2 = .085$, indicating a large effect of the PBEL model in enhancing this dimension. About the cognitive engagement dimension, a significant difference was found with $F_{(1,91)} = 9.70$, $p = .003$, and $\eta^2 = .096$, which was the largest effect contribution among the four dimensions. Meanwhile, skill engagement also showed a significant difference between groups with $F_{(1,91)} = 5.22$, $p = .025$, and $\eta^2 = .054$. The findings reinforce that implementing the PBEL model is significantly more effective than PJBL in enhancing student engagement in all aspects, with the most prominent effects on cognitive and emotional engagement.

Table 9. ANCOVA Results for Each Engagement Dimension.

Dimension Engagement	$F_{(1,91)}$	p	η^2
Behavioral engagement	6.72	0.012	0.069
Emotional engagement	8.45	0.004	0.085
Cognitive engagement	9.70	0.003	0.096
Skills engagement	5.22	0.025	0.054

Post hoc analysis through pairwise comparisons test with Bonferroni adjustment pointed out significant differences between PBEL and PjBL groups on all dimensions of student engagement (see Table 10 and Figure 3). The mean difference of 0.35 ($SE = .12$) for the behavioural engagement dimension was significant, with $p = .014$ and a 95% confidence interval [.07, .63]. A mean difference of .38 ($SE = .11$) was recorded for emotional engagement, significant at $p = .006$ with 95% CI [.10, .66]. A larger difference emerged on the cognitive engagement dimension with a mean difference of .42 ($SE = .11$), $p = .003$, and a 95% confidence interval [.14, .70]. Meanwhile, a significant difference of .40 ($SE = .14$), $p = .019$, with 95% CI [.06, .74] was found on skill engagement.

Table 10. Pairwise Comparisons (Bonferroni adjusted) Between PBEL and PJBL on each Engagement Dimension.

Dimension	Mean Difference	SE	p	95% CI
Behavioral engagement	0.35	0.12	0.014	[0.07, 0.63]
Emotional engagement	0.38	0.11	0.006	[0.10, 0.66]
Cognitive engagement	0.42	0.11	0.003	[0.14, 0.70]
Skills engagement	0.40	0.14	0.019	[0.06, 0.74]

The results of pairwise comparisons and estimated marginal means tests consistently proved that students who studied with the PBEL model had higher levels of engagement than PjBL on all dimensions, with the most pronounced effects seen in cognitive and emotional engagement. The finding further strengthens the effectiveness of PBEL in comprehensively improving the quality of multidimensional student' engagement.

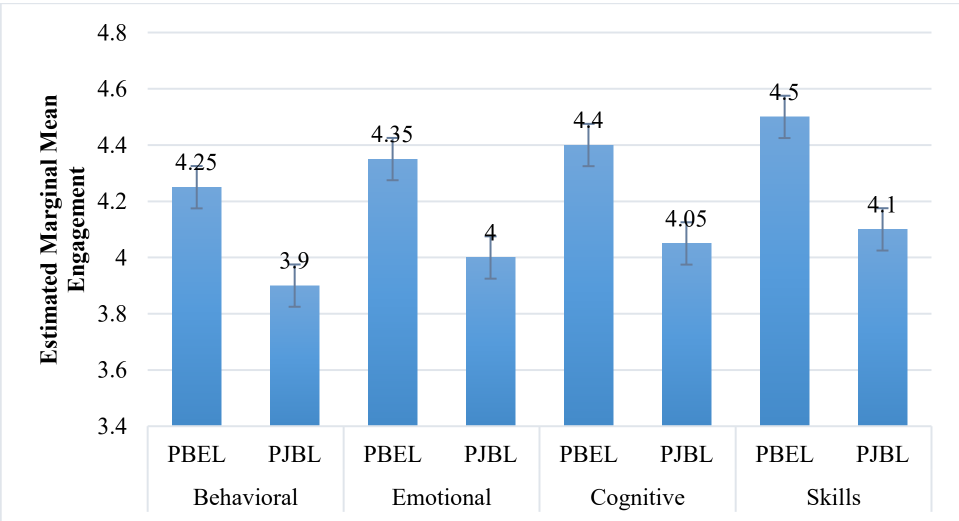

Figure 3. Estimated Marginal Means of each Engagement Dimension.

DISCUSSION

Interpretation of PBEL over PJBL in Promoting Multidimensional Engagement: Insights and Implications

Addressing RQ1, the ANCOVA analysis results confirm that the PBEL model is generally more effective than the PjBL model in enhancing students' multidimensional engagement in indigenous knowledge-based science learning. Specifically, PBEL produced statistically significantly higher posttest scores than PjBL on all dimensions of student engagement. The ANCOVA findings were presented through adequate *F* values and significance in each dimension, with the most substantial effect seen in cognitive engagement ($F_{(1,92)} = 9.70$, $p = .003$, $\eta^2 = .095$) and emotional engagement ($F_{(1,92)} = 8.45$, $p = 0.004$, $\eta^2 = 0.084$). The abovementioned points indicate that PBEL encourages students to think more deeply and integrate concepts critically and fosters their enthusiasm and emotional interest in the material being taught. Meanwhile, on the dimensions of behavioural engagement ($F_{(1,92)} = 6.72$, $p = .012$, $\eta^2 = .067$) and skills engagement ($F_{(1,92)} = 5.22$, $p = .025$, $\eta^2 = .053$), the effect of PBEL was also significant. However, the effect size was relatively smaller than the previous two dimensions.

The research findings consistently support the theoretical framework proposed by Fredricks et al. (2004), which asserts that student engagement is multidimensional, including behavioural, emotional, cognitive, and skill dimensions, which interact with each other in influencing the learning process. The results also align with previous studies, confirming that the PjBL approach can enhance students' behavioural and cognitive engagement because it emphasizes hands-on activities and authentic problem-solving (Mebert et al., 2020; Zen et al., 2022). However, the developed PBEL model indicates a further trend, as it contributes significantly to emotional and skill engagement. It is inseparable from integrating Indigenous knowledge, that is, the context of making herbal medicine, which is scientifically relevant and close to students' cultural identity, to foster a sense of belonging, pride, and higher enthusiasm in the learning process. The finding reinforces the reports of other studies, such as Ojalehto et al. (2017) and Martín (2015), who found that using indigenous knowledge in science learning can enhance motivation and positive affection and bridge students' conceptual understanding.

The advantages of the PBEL model compared to PjBL are theoretical; PBEL combines real projects, hands-on experiments, and the context of indigenous knowledge, thus facilitating students' multidimensional involvement more fully. Referring to the framework of self-determination theory (Manninen et al., 2022), PBEL supports students' needs for autonomy, competence, and connection to their cultural context, which triggers curiosity, personal meaning, and a sense of relevance to the material being studied. Meanwhile, according to the situated learning perspective (Renkl, 2001), learning integrated with local cultural practices such as herbal medicine not only provides contextual experiences (Harfouche et al., 2021) but also strengthens students' cultural identity and pride, thus naturally increasing emotional engagement (Linger, 2017). From the practical side, hands-on activities in hands-on experiments, from identifying the morphology of ingredients, boiling, and measuring pH to presenting herbal medicine products, directly train students' procedural skills, which contribute to increased skills engagement (Harfouche et al., 2021; Linger, 2017; Ojalehto et al., 2017; Templeman et al., 2018). The combination of these elements makes PBEL more effective in fostering student engagement behaviorally, emotionally, cognitively, and skills beyond the achievements of PjBL, which tend to be more limited to aspects of project activities and problem-solving.

The developed PBEL model's prominent uniqueness is its integration with indigenous knowledge, primarily through the context of making herbal medicine, which utilizes Indonesia's biological and cultural wealth as a living laboratory of ethnoscience (Rahmawaty, 2020). With its diverse flora, traditional medicine practices, and herbal medicine consumption traditions passed down for generations, Indonesia provides an ideal foundation for linking science learning with authentic local knowledge (Food and Agriculture Organization, 2020). The approach not only strengthens the relevance of the material to students' lives but also fosters a sense of belonging and cultural pride that contributes to emotional and affective engagement in the learning process (Harfouche et al., 2021; Linger, 2017; Ojalehto et al., 2017; Templeman et al., 2018). The PBEL design combines projects, scientific experiments, and indigenous knowledge and offers a pedagogical framework that can be replicated or adapted by other developing countries rich in local wisdom.

Consistency of PBEL Impact Across University Contexts

Addressing RQ2, the results of the two-way ANCOVA analysis proved that there was a significant main effect of learning model on students' overall engagement ($F_{(1,90)} = 15.32$, $p = .0002$, $\eta^2 = .142$), with PBEL resulting in higher mean engagement scores (EMM = 4.38; 95% CI [4.22, 4.54]) than PjBL (EMM = 4.01; 95% CI [3.85, 4.17]). However, no significant main effect of the university was found ($F_{(2,90)} = .64$, $p = .529$, $\eta^2 = .014$), indicating that students' average overall engagement was relatively uniform across the three universities (UNS, UMS, UNIVET) after controlling for the pretest. Furthermore, the analysis also found no significant interaction between the learning model and the university ($F_{(2,90)} = .39$, $p = .678$, $\eta^2 = .009$). The finding indicates that the effectiveness of

PBEL in enhancing students' multidimensional engagement was consistent across the three universities despite slight variations in mean scores across campuses.

The consistent effect of the PBEL model in enhancing students' multidimensional engagement across the three universities involved can be explained by several interrelated factors. First, the study programs in the research context are all Elementary School Teacher Education, which has a similar national curriculum in Elementary Science Education courses, thus providing a relatively homogeneous competency foundation and learning structure. Second, the characteristics of students at the three universities also show a similar profile, especially in terms of limited prior experience in science. Hence, the PBEL approach integrating real projects, hands-on experiments, and ethnoscience contexts becomes equally relevant and provides more interesting learning stimulation across locations (He et al., 2023; Krajcik & Blumenfeld, 2020).

Furthermore, using Indigenous knowledge in the form of herbal medicine-making practices close to Indigenous traditions also triggers curiosity, cultural pride (Dabaghian et al., 2023), and student enthusiasm without being significantly affected by institutional differences (Martín, 2015). While the PBEL model generally demonstrated consistent effectiveness in enhancing students' multidimensional engagement across the three universities, the descriptive data revealed minor variations, such as slightly higher average engagement scores at UNS compared to UMS and UNIVET. The minor variations may be caused by several contextual factors that deserve attention. One of them is the possibility of differences in laboratory facilities or experimental support facilities, which can affect the smoothness and quality of students' hands-on experience in carrying out the herbal medicine project (Ayuttacorn, 2024; Latai-Niusulu et al., 2024; Michie et al., 2023). Moreover, lecturers' pedagogical support, such as the quality of guidance, motivation to integrate Indigenous knowledge contexts and scaffolding strategies, also contribute to differences in engagement outcomes between campuses (Gauvain, 2020; Seel, 2017). Equally important, the academic culture of each university, including traditions of scientific discussion or group work habits (Al-Kamzari & Alias, 2025; Teresa & Fields, 2023), may influence the extent to which students feel comfortable and enthusiastic about engaging in innovative project-based learning. Although the differences are relatively small and not statistically significant, these findings underscore the need to pay attention to institutional factors and campus culture in implementing PBEL to achieve optimal outcomes in various higher education contexts.

The Unique Contribution of Indigenous Knowledge to Emotional and Skills Engagement

In line with RQ3, the results of further analysis through ANCOVA for each dimension revealed that applying the PBEL model had a positive impact in general and specifically made the most significant contribution to enhancing students' emotional engagement and skills engagement. The highest η^2 values are reflected in emotional engagement ($F_{(1,91)} = 8.45, p = .004$) and skills engagement ($F_{(1,91)} = 5.22, p = .025$), compared to other dimensions. The results of further comparison test (Bonferroni adjusted) also emphasized a significant mean difference between PBEL and PJBL on both dimensions, respectively by .38 ($SE = .11, p = .006$) on emotional engagement, and .40 ($SE = .14, p = .019$) on skills engagement. The findings indicate that integrating Indigenous knowledge through the herbal medicine-making project in PBEL promotes effective engagement among students while strengthening practical skills in scientific procedures.

Integrating indigenous knowledge in science learning can facilitate students' emotional and skill engagement. Within the engagement framework (Fredricks et al., 2004; Kuh, 2009), emotional engagement includes enthusiasm, interest, and a sense of belonging to learning activities. The connection of science learning to Indigenous knowledge close to the student's cultural identity, such as the tradition of concocting herbal medicine passed down for generations, creates a sense of pride, curiosity, and personal relevance that deepens emotional engagement. The idea aligns with meaningful learning in situated learning (Renkl, 2001), emphasizing the importance of social and cultural context in building meaningful learning experiences. Moreover, engagement in the skills dimension is also optimally facilitated through the hands-on practice of making herbal medicine that involves scientific procedures such as ingredient identification, extraction, pH measurement, and filtration. The hands-on activities not only train scientific procedural skills but also hone manual skills relevant to local communities' daily lives, thus strengthening knowledge transfer in real contexts (Harris et al., 2015; Juuti et al., 2021; Miller et al., 2021).

Research contributes to overcoming the gaps in conventional learning methods still widely found in higher education, especially in science learning. Several studies show that learning dominated by teacher-centred approaches, such as lectures or procedural standard practicums, tends to be less effective in facilitating full student involvement. The meta-analytic study by Blegur et al. (2023) and the findings of Zhang et al. (2021) confirm that traditional instructional approaches often suppress curiosity, creativity and collaboration, thus failing to generate deep interest in learning. Although research on PjBL and various active learning strategies have been widely conducted and proven to increase behavioural and cognitive engagement (He et al., 2023; Krajcik & Blumenfeld, 2020), few studies explicitly integrate Indigenous knowledge in modern learning designs. Almost none have examined its impact separately on the dimensions of emotional engagement and skills engagement, which in this context are shown to have the most prominent effects.

IMPLICATIONS AND FURTHER RESEARCH

The study results provide practical implications for curriculum development and pedagogical innovation in higher education, especially in education and science programs. Integrating indigenous knowledge in the PBEL model points to a better tendency to be a pedagogical strategy to increase affective engagement, which is the emotional involvement of students that is often neglected in conventional learning designs. The results extend the understanding of how self-determination and situated learning can reinforce each other in the context of indigenous knowledge-based science learning, which has rarely been explored empirically in student populations in developing countries. Future research is recommended to test the PBEL model in other disciplines and more varied indigenous knowledge contexts to ensure the generalizability of these findings across learning domains and cultures.

CONCLUSIONS

The research conclusion confirms the theoretical framework of multidimensional engagement (Fredricks et al., 2004), self-determination theory (Manninen et al., 2022), and situated learning (Renkl, 2001) that project-based experiential learning in the context of local culture can fulfil students' basic needs for autonomy, competence, and social connectedness, as well as placing learning in a personally and socially meaningful context. The results of the ANCOVA analysis revealed that PBEL was preeminent over PjBL in enhancing all dimensions of student engagement and controlling initial academic achievement. The highest effects were seen in cognitive ($F_{(1,92)} = 9.70$, $p = .003$, $\eta^2 = .095$) and emotional ($F_{(1,92)} = 8.45$, $p = .004$, $\eta^2 = .084$) engagement, indicating PBEL's ability to promote deep conceptual understanding while increasing students' affective investment in the learning process. The two-way ANCOVA results highlighted that the effectiveness of PBEL in enhancing students' overall engagement scores was statistically significant ($F_{(1,90)} = 15.32$, $p = .0002$, $\eta^2 = .142$) and consistent across the three universities involved. No significant interaction between the learning model and the institution was found, indicating that the positive impact of PBEL is stable across institutional contexts. Further analysis of each dimension indicated that integrating Indigenous knowledge in PBEL specifically contributed most prominently to enhancing students' emotional engagement and skills. The consistency of the effectiveness of PBEL across the three universities also indicates the potential of the model to be replicated in diverse higher education contexts. Further research is recommended to test the applicability of PBEL with a variety of other indigenous knowledge contexts and in different fields of study to expand this model's generalizability and theoretical contribution.

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