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Mixing a science, technology and local wisdom model for Physical Education: effects on motivation, interest, and cultural awareness

Integración de ciencia, tecnología y sabiduría local en la Educación Física: efectos sobre la motivación, el interés y la conciencia cultural

Winara[1], Khairul Usman[1], Septian Prawijaya[1], Syahrial[1], Ummu Haniyyah[2], Muhammad Ikhlas[1]

[1]Department of Primary School Teacher Education, Faculty of Education, Universitas Negeri Medan, Indonesia

[2] Department of Biology Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Indonesia

*Correspondence: winara@unimed.ac.id

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Abstract

This study is grounded in the need to integrate interdisciplinary and contextual approaches into physical education instruction. The objective was to develop and evaluate instructional materials that incorporate science, technology, and local cultural wisdom to enhance students' learning outcomes, motivation, interest, and cultural awareness. A research and development design was employed, involving expert validation, small-scale trials, and full-scale implementation with 345 university students assigned to experimental and control groups. Validated questionnaires and both descriptive and inferential analyses were used. Results indicated that the experimental group achieved significantly higher learning outcomes than the control group (t = 11.82, p < .001, Cohen's d = 1.14). Students in the experimental group also showed substantial pre–post improvement (ΔM = 11,06). Motivation, interest, and cultural awareness were significantly correlated with learning outcomes *(*r = .68–.77) and jointly predicted 54.4% of the variance in academic performance (R^2 = .544, p < .001). These findings demonstrate that integrating science, technology, and local culture into physical education enhances learning quality and strengthens contextual relevance. This model is recommended for broader institutional adoption, with longitudinal research suggested for future validation.

Keywords: physical education; motivation; interest; cultural awareness; educational innovation

Resumen

Este estudio se fundamenta en la necesidad de integrar enfoques interdisciplinarios y contextuales en la enseñanza de la educación física. El objetivo fue desarrollar y evaluar materiales didácticos que incorporaran ciencia, tecnología y sabiduría cultural local para mejorar los resultados de aprendizaje, la motivación, el interés y la conciencia cultural de los estudiantes. Se empleó un diseño de investigación y desarrollo que incluyó validación por expertos, pruebas a pequeña escala e implementación a gran escala con 345 estudiantes universitarios distribuidos en grupos experimental y de control. Se utilizaron cuestionarios validados, así como análisis descriptivos e inferenciales. Los resultados indicaron que el grupo experimental obtuvo resultados de aprendizaje significativamente superiores en comparación con el grupo de control (t = 11.82, p < .001, d de Cohen = 1.14). Los estudiantes del grupo experimental también mostraron una mejora pre–post sustancial (ΔM = 11.06). La motivación, el interés y la conciencia cultural se correlacionaron de manera significativa con los resultados de aprendizaje (r = .68–.77) y predijeron conjuntamente el 54.4% de la varianza en el rendimiento académico (R^2 = .544, p < .001). Estos hallazgos demuestran que la integración de la ciencia, la tecnología y la cultura local en la educación física mejora la calidad del aprendizaje y fortalece su relevancia contextual. Se recomienda la adopción institucional más amplia de este modelo y se sugiere realizar investigaciones longitudinales para su validación futura.

Palabras clave: educación física; motivación; interés; conciencia cultural; innovación educativa

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Introduction

The dynamic evolution of educational demands in the 21st century, accelerated by the advancement of science and technology, calls for innovative instructional approaches across disciplines, including physical education (Webster et al., 2021; T. Zhang & Fu, 2022). As the world transitions from the Industrial Revolution 4.0 to Society 5.0, the integration of digital and scientific literacy into education has become a necessity (Jia, 2021; Usman et al., 2022). Education is now expected to prepare learners to adapt to rapid technological change and respond to complex social and cultural challenges. However, physical education in many contexts remains rooted in traditional, one-size-fits-all methods that overlook the potential of integrating science, technology, and local wisdom (Ma, 2021). Embracing an interdisciplinary approach that combines physical activity, scientific understanding, technological tools, and cultural values is crucial to making physical education more relevant, engaging, and transformative for 21st-century learners.

Integrating science and technology into physical education offers opportunities to deepen students' understanding of bodily movement, health principles, and the scientific basis of physical activity (D'Oliveira et al., 2022; Ravn, 2022). Simultaneously, embedding local cultural values, such as traditional games and indigenous sports, can foster a stronger sense of identity, belonging, and contextual relevance in learning. Local wisdom, often described as community-based knowledge, values, and practices based on cultural heritage (Hasan et al., 2024), is the source of numerous learning contexts that tie physical education to students' familiar environments (Kusuma et al., 2021). Local wisdom has several benefits, including the need to preserve a cultural identity, the opportunity to increase motivation, and the focus on culturally responsive pedagogy. Yet, the challenges include the lack of proper documentation and the risk of local wisdom failing to align with the latest curricula or having other meanings across regions. When modern knowledge systems intersect with local wisdom, students are more likely to engage meaningfully with learning materials, seeing them as both relevant and inspiring (Kurniawan & Kuswanto, 2021; Suprapto et al., 2021). This dual approach not only enriches the cognitive and physical dimensions of learning but also strengthens emotional and cultural connections. Ultimately, it promotes a more holistic educational experience

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that prepares students to navigate both global challenges and local realities with confidence and competence.

In Indonesia, particularly within primary school teacher education programs, the development of physical education materials remains relatively stagnant (Haryani et al., 2021; Wahyuni et al., 2024). Existing instructional resources often overlook the importance of culturally responsive teaching and the integration of relevant scientific knowledge and technological tools. This misalignment may lead to missed opportunities in fostering not only physical literacy but also cognitive engagement, motivation, and cultural identity among students. Without meaningful updates to instructional approaches, physical education risks becoming disengaging and disconnected from students' lived experiences (C.-M. Chang et al., 2021; Haegele & Maher, 2022). Therefore, there is a pressing need to modernize physical education curricula by incorporating interdisciplinary methods that bridge scientific understanding, technological advancements, and local cultural heritage.

The relevance of incorporating local wisdom into physical education is twofold. First, it connects students with traditional values and heritage, reinforcing their cultural identity (Pamungkas & Manaf, 2023). Second, it offers opportunities to reframe traditional games and movements into scientifically rich and technologically enhanced learning activities (Estevan et al., 2023). When physical education materials embed both local and modern elements, students may experience greater relevance, engagement, and long-term retention of knowledge and skills (de Andrade et al., 2024; X. Zhang & Ma, 2024). This fusion not only supports holistic development but also aligns with educational goals that emphasize contextualized, student-centered learning. Moreover, it encourages future educators to design innovative instructional practices that honor cultural authenticity while embracing scientific progress.

Prior studies have highlighted that effective physical education is grounded in comprehensive curricula, contextually appropriate instruction, and robust student assessment strategies (Bai et al., 2024; Schlegel & Křehký, 2024). Moreover, educational design research has emphasized the value of culturally situated instructional development, particularly in teacher education, to promote pedagogical competence, affective engagement, and learner autonomy (Li, 2023; Mahadew & Hlalele, 2022).

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These findings underscore the importance of aligning educational content with learners' sociocultural contexts to maximize instructional impact. In the realm of physical education, this alignment is particularly crucial given its embodied, participatory, and socially embedded nature.

To respond to this need, this study aims to develop and implement physical education instructional materials that are enriched with science, technology, and local wisdom. The materials are specifically designed for primary school teacher education students as prospective elementary school teachers. The implementation of the product is assessed for its effectiveness in improving learning outcomes and enhancing students' motivation, interest, and awareness of local culture in the context of physical education. Motivation and interest are key psychological factors that influence how students interact with learning experiences (Alsadoon et al., 2022; Park & Kim, 2022). In physical education, these factors become particularly salient, as active participation and consistent effort are essential for meaningful outcomes. Instructional materials that stimulate interest and nurture intrinsic motivation are more likely to produce positive learning behaviors and outcomes (Esmaeil et al., 2024; Wang et al., 2024). Moreover, when students recognize their own cultural heritage within the content, it can enhance their sense of purpose and pride, further reinforcing engagement and achievement.

For prospective elementary school teachers, these experiences are foundational. Their exposure to innovative and contextually relevant materials during teacher preparation influences not only their academic success but also their future instructional choices (Lee & Hwang, 2022; Ozturk-Akar, 2023). Despite the growing number of studies that integrate local cultural contexts and technology in subjects such as science and mathematics, similar developments have not been adequately explored in physical education, particularly within teacher education programs in Indonesia. Existing research in physical education tends to treat cultural content, scientific principles, and technological tools separately, resulting in limited interdisciplinary instructional models. Unlike other subjects that have begun adopting culturally contextualized and technology-supported learning resources, physical education still lacks a comprehensive, evidence-based model that unifies these three dimensions. Therefore, an explicit gap remains in developing and empirically evaluating culturally grounded, science-informed, and

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technology-enhanced instructional materials for physical education. This study directly responds to this disciplinary gap by developing, validating, and evaluating an interdisciplinary set of instructional materials for physical education that intentionally integrates scientific principles, relevant technological tools, and local cultural wisdom within a cohesive learning framework. Then, providing teacher candidates with physical education resources that bridge science, technology, and cultural identity is a strategic step in preparing educators who are both pedagogically competent and culturally responsive. This study addresses the need for such integrative instructional design by developing materials that combine physical education content with elements of science, technology, and local wisdom. By doing so, the study also explores how these materials influence key learner attributes such as motivation, interest, and cultural awareness, and how these attributes relate to students' academic performance in physical education.

Research Objectives

This study aims to develop, implement, and evaluate science- and technology-based physical education instructional materials that incorporate elements of local wisdom for preservice primary school teachers. Specifically, the study seeks to develop interdisciplinary instructional materials that integrate scientific principles, technological tools, and culturally grounded knowledge to enhance contextualized learning in physical education. It also examines the effectiveness of these materials in improving students' learning outcomes compared to conventional instructional approaches. Furthermore, the study evaluates the extent to which students' learning outcomes improve after participating in an experimental teaching intervention using the developed materials. In addition, the research investigates the relationships between students' motivation, interest, and local cultural awareness and their learning outcomes in physical education. Finally, the study assesses the predictive contribution of motivation, interest, and local cultural awareness to students' academic performance in physical education.

Hypothesis

Based on the research objectives and the measured variables, this study proposes several hypotheses to guide the statistical analyses. First, it is hypothesized that students

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who receive the science and technology-based physical education materials integrating local wisdom will demonstrate significantly higher learning outcomes than those who receive conventional instruction (H1). It is also hypothesized that learning outcomes among students in the experimental group will significantly increase after engaging with the developed instructional materials (H2). Furthermore, the study posits that students' motivation, interest, and local cultural awareness will each have significant correlations with their learning outcomes in physical education (H3). Finally, it is hypothesized that the three variables, such as motivation, interest, and local cultural awareness, will function as significant predictors of students' academic performance in physical education (H4).

Methods

This study employed a Research and Development design, integrating both product development and experimental validation stages. Research and Development is defined as a methodological approach aimed at designing, refining, and testing educational products to ensure their effectiveness and feasibility in real-world contexts (Gall et al., 1996; Mustakim et al., 2024). In the initial stage, a physical education teaching material product was designed by integrating elements of science, technology, and local wisdom tailored to elementary education. The purpose of this product was to enhance students' learning outcomes while promoting motivation, interest, and cultural awareness. The feasibility and appropriateness of the developed product were evaluated by a panel of experts comprising one subject matter expert, one media specialist, and three lecturers. In addition, feedback was gathered from 345 undergraduate students from the Primary School Teacher Education Department, Universitas Negeri Medan, who were enrolled in the Elementary Physical Education course during the odd semester of the 2023/2024 academic year. This initial stage focused on iterative design revisions based on expert and student input.

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Figure No. 1 Development Research Flow Chart

Following the development and validation stages, an implementation phase was conducted using a quasi-experimental design to assess the effectiveness of the product. The participants included third-semester students, distributed across eight naturally formed classes. Four classes were assigned to the experimental group and received instruction using the developed teaching material, while the remaining four classes served as the control group and followed the conventional teaching approach.

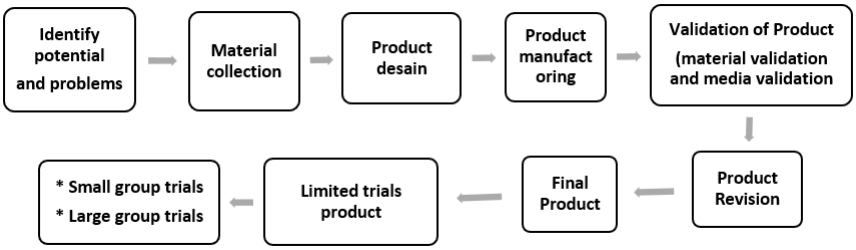

Figure No. 2 Model of Science and Technology-Based Physical Education Material with Local Wisdom for Primary School Teacher Education

Participants

The participants involved in this study were categorized into three main groups: expert validators, trial participants, and the main experimental-control group sample. Three expert validators were recruited to assess the feasibility and appropriateness of the developed instructional product. A small-scale trial was conducted with 30 preservice primary school teachers who provided feedback regarding the practicality and clarity of the instructional material. This phase served to refine the product before broader implementation. Following this, a large-scale trial was carried out involving 173 students, representing four classes assigned to the experimental group. These participants engaged with the finalized product during the regular course of instruction.

Furthermore, in the implementation step, the sampling technique employed was purposive sampling, targeting preservice elementary school teachers enrolled in the third

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semester who were taking a physical education course. This specific population was chosen based on the relevance of the instructional product to the course content and the students' academic readiness to engage with the integrated materials combining science, technology, and local wisdom.

Table No. 1 Demographic profile of the participants

Demographic Information	Description
Age	Mean = 19.17, SD = 0.67 (range = 18-21)
▪ 18	29 (8.41%)
▪ 19	254 (73.62%)
▪ 20	38 (11.01%)
▪ 21	24 (6.96%)
Gender	
▪ Male	29 (8.41%)
▪ Female	316 (91.59%)
Ethnic/Cultural Background	
▪ Toba Batak	119 (34.49%)
▪ Javanese	64 (18.55%)
▪ Mandailing Batak	54 (15.65%)
▪ Malay	32 (9.28%)
▪ Karo Batak	19 (5.51%)
▪ Nias	24 (6.96%)
▪ Minangkabau	14 (4.06%)
▪ Simalungun Batak	8 (2.32%)
▪ Sundanese	6 (1.74%)
▪ Acehnese	5 (1.45%)
Academic Background	Third-semester preservice elementary school teachers
Prior Experience in PE	▪ previously studied PE (throughout elementary to high school); ▪ and completed the Elementary School Physical Education course (semester 2) as a requirement for taking the Elementary School Sport Education course (semester 3, during this program)

The total sample consisted of 345 students, drawn from eight existing classes. Of these, four classes were assigned to the experimental group, in which the innovative instructional product was implemented, while the remaining four classes served as the control group and received conventional instruction. Each class comprised approximately 40 to 45 students. Table 1 illustrates the demographic profiles of the participants.

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Demographically, participants were aged between 18 and 21 years (M = 19.17, SD = 0.67), and the majority were female (approximately 91,59%), reflecting the typical gender distribution in primary teacher education programs. All participants shared similar educational backgrounds as undergraduate students in the third semester of a primary education program. All participants had prior exposure to physical education as part of their formal schooling from elementary to senior high school, following the national curriculum. At the tertiary level, they had completed the Elementary School Physical Education course in the previous semester. During this study, they were enrolled in the Elementary School Sports Education course, which builds upon the foundational knowledge and pedagogical understanding gained earlier. Participants represented diverse ethnic and socio-cultural backgrounds common to the local province, where they came from ten different ethnic groups in North Sumatra, Indonesia, providing relevant cultural perspectives for the integration of local wisdom in the learning materials. Table 2 summarizes the group distribution and the number of students in each class. This sampling approach ensured that all participants shared similar academic backgrounds and were engaged in comparable course content, thereby enhancing the validity of comparisons between the experimental and control groups.

Table No. 2 Overview of Participants in Experimental and Control Groups

Group	Class Code	Total
Experimental (n=173)	E1	42
	E2	44
	E3	44
	E4	43
Control (n=172)	C1	45
	C2	42
	C3	44
	C4	41
Total		345

Ethical Considerations

This study complied with institutional ethical standards for educational research. Ethical clearance was obtained through the university's internal research grant approval process, which included institutional permission from the faculty level. All participating students

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were informed about the study's objectives, procedures, and their rights as participants. Participation was voluntary, and students could withdraw at any time without academic consequences. Informed consent was obtained prior to data collection. All responses were kept confidential and were used solely for research purposes in accordance with institutional research ethics guidelines.

Instruments

The data collection techniques used in this study included interviews, questionnaires, validation sheets, and documentation of students' final scores. The instruments consisted of interview sheets for lecturers and students, validation sheets completed by material and media experts, as well as response questionnaires for students. Needs analysis data were gathered through observation and interviews. The validation sheets were used to assess the feasibility of the product by experts. Based on the experts' feedback, revisions were made accordingly. After the revisions, a practicality test was conducted prior to implementing small-scale and large-scale trials. Furthermore, this study also utilized a combination of adapted and course-based instruments to measure four key variables such as motivation, interest, cultural awareness, and learning outcomes. The instruments for motivation, interest, and cultural awareness were adapted from previously validated scales, while learning outcomes were measured using students' final scores in the physical education course.

Motivation was assessed using a four-item scale developed by Lonsdale et al. (2011), designed to capture intrinsic and autonomous motivation specifically within educational contexts. Items were rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Interest was measured using a 14-item scale adapted from Roure et al. (2021), covering both situational and individual interest in learning activities, also rated on a 5-point Likert scale. The original instrument includes three sub-indicators, such as positive affect and willingness to reengage, stored tility value, and stored attainment value with knowledge-seeking intentions. For this study, the scale was treated as a unified construct to capture overall interest in physical education. Minor wording adjustments were made to ensure linguistic clarity and contextual relevance for university students. Furthermore, to assess students' cultural awareness, a 4-item scale adapted from

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Atai et al. (2017) was employed, reflecting students' sensitivity, understanding, and appreciation of local cultural values in educational settings, with a 5-point Likert scale as well.

To ensure that these instruments were suitable for the Indonesian context, the scales were subjected to a back-translation process. The back-translation method, commonly used in cross-cultural research, involved translating the instruments from the original language (English) into Indonesian and then back into English by independent bilingual translators. This process helped ensure the accuracy of the translation and the equivalence of the constructs being measured in both languages. After translation, a group of Indonesian experts reviewed the instruments for cultural relevance and appropriateness, ensuring that the items were contextually aligned with the Indonesian educational environment.

Reliability was assessed using Cronbach's Alpha, and the results indicated that each scale demonstrated acceptable internal consistency, with α coefficients ranging from 0.78 to 0.89. These values meet the minimum reliability threshold for educational research instruments, thereby supporting their use in the main study. Table 3 summarizes the variables, number of items per instrument, examples of the items, sources, and Cronbach's Alpha reliability coefficients.

Table No. 3 Instrument Summary and Reliability Statistics

Variable	Number of Items	Sample**	Source	α
Motivation	4	Because I feel good when I am actively involved in PE activities.	Lonsdale et al. (2011)	0.81
Interest	14	I enjoy physical education and would like to have more PE classes.	Roure et al. (2021)	0.89
Cultural Awareness	4	I understand that physical education activities can reflect local traditions and cultural values.	Atai et al. (2017)	0.78
Learning Outcomes*	Final score	-	Course-based evaluation	-

*Cronbach's Alpha does not apply to the learning outcomes variable as it is based on course-based summative assessment.
**Only sample items are shown for brevity; full item sets are available upon request.

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Data Analysis Technique

In the development step, two main types of data analysis were employed in this study: content validity analysis and effectiveness analysis. To assess the content validity of the developed textbook, expert judgments were analyzed using Aiken's V coefficient (Aiken, 1985; Ventura-León et al., 2025) . Each expert evaluated the textbook using a four-point scale (1 = not relevant, 4 = highly relevant) across five key aspects: alignment with learning outcomes, conceptual accuracy, integration with local wisdom, language clarity, and visual presentation. The Aiken's V value was calculated using the following formula:

$$V = \frac{\sum s}{n(c-1)}$$

Where,

V: Aiken's validity coefficient (ranges from 0 to 1).

s: The score given by each expert, adjusted by subtracting the lowest score possible.

$$s = r - l\,;$$

r: The rating given by an expert.

l: The lowest score on the rating scale (e.g., if using a 1–5 scale, then $l = 1$)

c: The number of points on the rating scale; and n: The number of experts

After that, the effectiveness of the textbook was analyzed using the Normalized Gain (N-Gain) formula as proposed by Hake (1998), to measure the relative improvement of students' learning outcomes from pretest to posttest, with formula:

$$N\ Gain = \frac{Posttest\ score - \ Pretest\ score}{Maximum\ score - Pretest\ score}$$

Meanwhile, the N-Gain scores were interpreted using the following category, such as, high ($g \geq 0.70$), medium ($0.30 \leq g < 0.70$), low ($g < 0.30$). Furthermore, regarding the

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implementation step, the data analysis in this study was conducted in two stages: descriptive and inferential. Descriptive statistics were used to present the general characteristics of the data across the four observed variables, learning outcomes, motivation, interest, and cultural awareness, for both experimental and control groups. The analysis included measures such as mean, standard deviation, minimum, and maximum values. Before proceeding to inferential statistics, the data were tested for compliance with the assumptions of parametric testing. Given the large sample size of 345 students across eight classes, the Kolmogorov–Smirnov test was applied to assess data normality. The results showed that all variables demonstrated acceptable levels of normality for parametric testing ($p > .05$). In cases where slight deviations were detected due to the sensitivity of the test at large sample sizes, parametric analyses were still considered appropriate as they remain robust under minor violations of normality (Sayili & Gunver, 2025). Additionally, Levene's Test was used to examine the homogeneity of variances between groups. The results showed that all variables met the homogeneity assumption ($p > .05$), indicating equal variances between the experimental and control groups.

Inferential statistics were applied to evaluate the effectiveness of the instructional product based on science, technology, and local wisdom. Changes within each group, experimental and control, were analyzed by comparing pretest and posttest scores using paired sample t-tests. This analysis aimed to determine whether there were statistically significant improvements in each variable after the treatment, particularly within the experimental group (Yu et al., 2022). Furthermore, to compare the performance between groups after the intervention, independent sample t-tests were conducted on the posttest scores of the experimental and control groups. These tests allowed the researchers to examine whether the observed differences in outcomes could be attributed to the intervention provided to the experimental group (Yu et al., 2022). In addition to statistical significance testing, effect sizes were calculated using Cohen's d for both paired and independent t-tests to assess the magnitude of the intervention's impact. The inclusion of Cohen's d provides a measure of practical significance, enabling interpretation of whether the improvements or group differences were small, moderate, or large in real educational contexts (Dudley et al., 2022; Panjeh et al., 2023).

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In addition, Pearson product–moment correlation analysis was conducted to examine the relationships between motivation, interest, cultural awareness, and learning outcomes. This test was used to determine the direction and strength of the linear associations among the variables (Prestes et al., 2021). Correlation coefficients *(r)* and significance values *(p)* were reported for interpretation. To further explore the predictive relationships between the independent variables, such as motivation, interest, and cultural awareness, and the dependent variable, namely learning outcomes, multiple linear regression analysis was conducted. This analysis provided insights into the extent to which each predictor variable, both individually and collectively, contributed to the variation in student learning outcomes. Standardized beta coefficients, significance values (p-values), and the adjusted R^2 were examined to interpret the strength and significance of the model(S. Liu et al., 2023). All statistical analyses were carried out using SPSS software, with a significance level set at $\alpha = 0.05$. The interpretation of results was based on p-values, complemented by differences in mean scores to estimate the practical effect of the intervention.

Theoretical Framework

The development of instructional materials for physical education that integrate science, technology, and local wisdom is grounded in several interrelated theoretical perspectives. These include constructivist learning theory, self-determination theory, culturally responsive pedagogy, and integrative curriculum design theory. Together, these frameworks offer a multidimensional understanding of how learners engage with content that is both intellectually stimulating and culturally meaningful. Constructivist learning theory posits that learners construct knowledge through active engagement with content that is meaningful and contextualized (Espinosa et al., 2024). In the context of physical education, this theory supports the idea that students learn best when they can connect new information to their prior experiences, including those rooted in local culture and community practices (Parsak et al., 2024). The inclusion of traditional games and culturally situated movement activities aligns with this view, providing authentic contexts for learning that can enhance both conceptual understanding and physical literacy.

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Complementing this is self-determination theory (SDT), which emphasizes the importance of intrinsic motivation, autonomy, and relatedness in driving learning behavior (Han & Graham, 2024; Ryan & Deci, 2000). Physical education, being inherently participatory and affective, is particularly influenced by students' levels of motivation and interest. Instructional materials that foster autonomy and relevance, by integrating science and technology with familiar cultural elements, are more likely to support intrinsic motivation (Kolovelonis et al., 2022). This theory underpins the hypotheses relating to the role of psychological factors such as motivation and interest in enhancing student learning outcomes.

The third pillar of this framework is culturally responsive pedagogy, which advocates for educational practices that are inclusive of learners' cultural backgrounds, identities, and experiences (W.-C. Chang & Viesca, 2022; Gay, 2002). This approach is especially relevant in teacher education, where future educators must be prepared to design and deliver instruction that is sensitive to the diverse cultural contexts of their students. Embedding local wisdom into physical education not only affirms students' identities but also models pedagogical practices that prospective teachers can adopt in their own classrooms (Kusuma et al., 2021). By recognizing and valuing the cultural assets that students bring into the classroom, culturally responsive teaching fosters a deeper sense of belonging, relevance, and engagement, which are key factors that enhance both motivation and learning outcomes.

Finally, integrative curriculum design theory supports the blending of disciplinary knowledge, such as science and technology, with traditional educational content to create richer and more meaningful learning experiences (Drake & Burns, 2004; Kreijkes & Greatorex, 2024). This theoretical lens emphasizes that learning is most effective when subject boundaries are deliberately interconnected, allowing students to perceive knowledge as a cohesive whole rather than fragmented parts. In the context of physical education, this means moving beyond a solely skill-based or activity-centered approach toward one that also incorporates scientific principles, technological tools (e.g., digital media, motion-tracking applications), and cultural relevance (e.g., traditional games and local practices).

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Results

This study focused on the development of a textbook for the Physical Education course aimed at prospective elementary school teachers. The development process adopted a modified version of the 4D model, Define, Design, and Develop, with the final phase, Disseminate, excluded from the scope of the current research. Each phase contributed systematically to the refinement and validation of the textbook as a pedagogical tool that integrates science, technology, and local wisdom within the context of physical education.

Define Phase: Needs and Problem Identification

The development process began with a comprehensive needs analysis, aiming to diagnose key problems in the sport education in elementary education course for prospective elementary school teachers. Data were collected through syllabus analysis, classroom observations, and informal interviews with both lecturers and students. The analysis revealed several issues, such as, lack of integration between textbook content and local culture, Inadequate alignment with learning outcomes, low student motivation and interest, and minimal contextualization of content to real-life primary school settings. These findings emphasized the need for a contextualized, culturally relevant, and pedagogically sound textbook to better support pre-service teachers in physical education instruction.

Design Phase: Blueprinting the Textbook

In this phase, a design framework was created to guide content development. The textbook was structured around thematic units that reflect the core competencies in the curriculum. Key instructional design principles used include, such as alignment with the learning outcomes for each chapter, the use of local sports and games to illustrate physical education concepts, embedded formative assessments and reflection tasks, and visual illustrations that reflect the students' sociocultural environment. Learning activities were designed to foster constructivist engagement, requiring students to analyze, reflect, and apply concepts in context. Figure 1 presents the cover of the developed instructional product. Figure 2 illustrates the integration of local cultural elements into physical

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education content through science and technology, enhancing contextual relevance and student engagement. Furthermore, Figure 3 displays examples of traditional games representing local wisdom that were incorporated into the instructional material as culturally grounded learning activities.

Figure No. 1 Cover of the developed instructional material

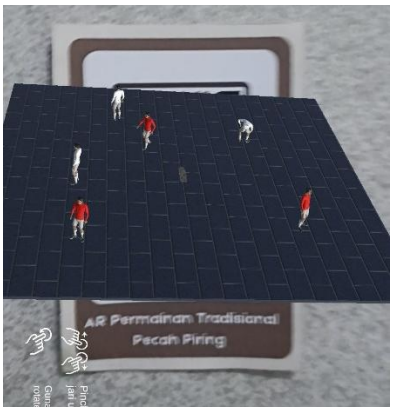

Figure No. 2 Example of local culture implementation in science and technology-based physical education activities.

Gambar 3. 1 Serompah

2. **Sumatera Utara**

Sumatera Utara adalah sebuah provinsi yang berada di bagian utata pulau Sumatera. Sumatera utara pada tahun 2020 memiliki jumlah penduduk sebanyak 14.799.361 jiwa dan

Figure No. 3 Example of traditional games (local wisdom) included in the developed instructional material

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Development Phase: Validation and Testing

Expert Validation

The developed textbook was evaluated by three expert validators. The validation focused on five core aspects using a 4-point Likert scale (1 = not relevant to 4 = highly relevant). The Aiken's V index was employed to assess the degree of agreement among the experts. The results of the content validation are summarized in the Table 4. All aspects received Aiken's V scores ranging from 0.78 to 0.89, indicating a moderate to high level of content validity. No aspect fell below the acceptable threshold of 0.70, suggesting a good degree of consensus among the expert panel.

Table No. 4 Aiken's V index result

No	Validation Aspect	Expert Ratings (r)	∑(r−1)	Aiken's V
1	Relevance to course learning outcomes	4, 4, 3	8	0.89
2	Conceptual and material accuracy	3, 3, 4	7	0.78
3	Integration with local wisdom	4, 3, 4	8	0.89
4	Language clarity and readability	4, 3, 3	7	0.78
5	Visual design and presentation	4, 3, 3	7	0.78

Small Group Trial

After revisions based on expert input, the textbook underwent a small group trial involving 30 students enrolled in the sports education in elementary school course. This phase served as a formative evaluation to assess the preliminary usability, content clarity, and pedagogical effectiveness of the developed textbook before proceeding to large-scale testing. Overall, students responded positively to the contextualized examples and visual elements, especially those involving traditional games and local sports. However, some suggestions were raised regarding the density of text in certain chapters and the clarity of instructions in task sections. Based on these insights, minor revisions were made, focusing particularly on simplifying sentence structures, improving layout consistency, and enhancing instruction prompts for reflective tasks. This trial confirmed that the textbook had strong initial acceptance and pedagogical potential, while also highlighting areas for refinement before broader implementation.

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Field Testing with Experimental and Control Groups

For the full-scale implementation, the textbook was tested on 173 students in four experimental classes (E1–E4), while 172 students in four control classes (C1–C4) continued using standard materials. Related to the effectiveness of the developed product, the analysis of normalized gain (N-Gain) indicated a medium level of effectiveness across all variables for the experimental group. Learning outcomes showed a gain of 0.468, while motivation, interest, and local cultural awareness exhibited gains of 0.534, 0.507, and 0.503, respectively, reflecting meaningful improvement following the use of the instructional product (see Table 5).

Table No. 5 N-Gain Score for Experimental Group

Variable	Pre	Post	N-Gain	Category
Learning Outcomes	76.35	87.41	0.468	Medium
Motivation	3.52	4.31	0.534	Medium
Interest	3.48	4.25	0.507	Medium
Local Cultural Awareness	3.43	4.22	0.503	Medium

Furthermore, the inferential statistics are presented following the research objectives and hypotheses. Paired sample t-tests showed significant improvements in all measured variables for the experimental group (see Table 6). Students who used the developed instructional product demonstrated a significant increase in their learning outcomes (from $M = 76.35$ to $M = 87.41$, $p < 0.001$), motivation (from $M = 3.52$ to $M = 4.31$, $p < 0.001$), interest (from $M = 3.48$ to $M = 4.25$, $p < 0.001$), and local cultural awareness (from $M = 3.43$ to $M = 4.22$, $p < 0.001$). Moreover, the large effect sizes (Cohen's d ranging from 0.98 to 1.25) indicate that these improvements are substantial and educationally meaningful. This demonstrates that the instructional product had a powerful influence on students' learning and engagement.

Table No. 6 Paired Samples t-Test for Experimental Group

Variable	Mean (Pre)	Mean (Post)	t	p-value	Cohen's d
Learning Outcomes	76.35	87.41	11.82	< .001	1.14
Motivation	3.52	4.31	9.27	< .001	1.03
Interest	3.48	4.25	10.91	< .001	1.25
Local Cultural Awareness	3.43	4.22	8.75	< .001	0.98

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Moreover, independent samples t-tests revealed that students in the experimental group significantly outperformed those in the control group in all measured variables (see Table 7). The mean score for learning outcomes in the experimental group was significantly higher ($M = 87.41$) than in the control group ($M = 76.32$), $p < 0.001$. The same pattern was observed for motivation, interest, and local cultural awareness, with all differences being statistically significant ($p < 0.001$). Importantly, the effect sizes were large across all variables (Cohen's $d = 0.80–1.15$), indicating a strong practical impact of the instructional product. This demonstrates that the developed material not only improves student performance but does so to a substantial degree compared to regular instruction.

Table No. 7 Independent Samples t-Test

Variabel	Mean (Exp)	Mean (Ctrl)	t	p-value	Cohen's d
Learning Outcomes	87.41	76.32	6.87	< .001	1.15
Motivation	4.31	3.65	5.92	< .001	0.88
Interest	4.25	3.58	6.34	< .001	1.11
Local Cultural Awareness	4.22	3.66	5.76	< .001	0.80

The Pearson correlation analysis examined the relationships between the predictor variables, motivation, interest, and local cultural awareness, and the dependent variable, learning outcomes. As shown in Table 8, the results demonstrate statistically significant and positive correlations among all the variables.

Table No. 8 Pearson Correlation Matrix among Variables

Variables	Variables		
	(2)	(3)	(4)
(1) Motivation	0.75**	0.72**	0.77**
(2) Interest		0.59**	0.74**
(3) Local cultural awareness			0.68**
(4) Learning outcomes			

Motivation showed a strong positive correlation with learning outcomes ($r = 0.76$, $p < 0.001$), followed closely by interest ($r = 0.74$, $p < 0.001$), and local cultural awareness ($r = 0.68$, $p < 0.001$). Additionally, the three predictor variables were also significantly

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intercorrelated. Motivation had a high correlation with interest (r = 0.75) and local cultural awareness (r = 0.72), while interest and local cultural awareness were moderately correlated (r = 0.59). These findings indicate that students who were more motivated also tended to be more interested in the subject and more aware of local cultural elements, all of which are associated with better academic performance in the integrated physical education course.

After that, the multiple linear regression was conducted to examine the predictive power of the three independent variables, such as motivation, interest, and local cultural awareness, on learning outcomes. The regression model was found to be statistically significant, $F_{(3, 169)} = 67.3$, $p < 0.001$, with an Adj R^2 value of 0.537. This indicates that approximately 53.7% of the variance in students' learning outcomes can be explained by the combined effect of the three predictor variables.

Table No. 9 Multiple Linear Regression Analysis Predicting Learning Outcomes (Experimental Group)

Model	Predictor variables	B	SE	*t*	sig
1	Constant	27.210	3.500	7.77	0.000
	Motivation	0.395	0.058	6.81	0.000***
	Interest	0.342	0.062	5.52	0.000***
	Local Cultural Awareness	0.317	0.054	5.87	0.000***
Model 1: $R^2 = 0.544$, Adj $R^2 = 0.537$, F (3,169) = 67.3.					
***Significant at $p < 0.001$					

As shown in Table 9, all three variables made significant contributions to the model. Motivation had the highest standardized beta coefficient ($\beta = 0.395$, $p < 0.001$), followed by interest ($\beta = 0.342$, $p < 0.001$), and local cultural awareness ($\beta = 0.317$, $p < 0.001$). These results suggest that while all three factors significantly influence learning outcomes, motivation is the strongest predictor among them.

Discussion

The results of this study provide robust evidence supporting the effectiveness of the instructional product developed by integrating science, technology, and local wisdom in physical education for preservice elementary teachers. The findings confirm that both cognitive (learning outcomes) and affective (motivation, interest, and local cultural

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awareness) domains of student learning were significantly enhanced through the implementation of the innovative teaching materials.

The analysis of content validity using Aiken's V coefficient confirms that the developed textbook is of high quality and relevance for its intended educational context. The highest levels of agreement were observed in the aspects of relevance to course learning outcomes and integration with local wisdom, both scoring 0.89. These results indicate that the textbook effectively addresses core competencies and provides culturally contextualized content, two critical elements for teacher preparation in physical education at the elementary level. The other aspects, such as conceptual accuracy, language clarity, and visual presentation, received Aiken's V values of 0.78, which fall within the acceptable range for educational material validation (Ventura-León et al., 2025). Although slightly lower than the top scores, these values still reflect solid expert consensus and do not suggest any serious deficiencies. Overall, the textbook is considered valid and feasible for implementation in instructional settings.

Concerning the effectiveness of the product, the medium N-Gain scores indicate that the integration of science, technology, and local wisdom into physical education materials had a positive and practical impact on students' knowledge and attitudes. Although the improvements are not categorized as "high," they reflect consistent and statistically significant progress, reinforcing the potential of the developed product to enrich learning experiences. This outcome suggests that contextualized and interdisciplinary approaches can effectively engage students and foster meaningful understanding. It also implies that even moderate gains, when consistently observed across a cohort, may signal deeper conceptual shifts rather than superficial memorization. Therefore, the integration strategy presents a promising direction for future curriculum development, particularly in culturally diverse educational settings.

Moreover, the increase in post-test scores of the experimental group highlights the pedagogical value of contextualized content. The use of local cultural elements, when interwoven with modern pedagogical strategies and relevant technologies, helped bridge the abstract concepts in physical education with students' lived experiences. This contextual relevance likely contributed to deeper understanding, retention, and application of the material, as reflected in the significant increase in learning outcomes.

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The role of motivation and interest as key drivers of academic performance is further reinforced in this study. Students in the experimental group demonstrated higher levels of enthusiasm, engagement, and willingness to participate in classroom activities. This suggests that the instructional design successfully addressed intrinsic motivational factors. These findings align with self-determination theory (Ryan & Deci, 2000), which emphasizes the importance of autonomy, competence, and relatedness in fostering motivation (Han & Graham, 2024). The learning activities were perceived as enjoyable and intellectually stimulating, which may have strengthened students' intrinsic desire to participate (Y. Kong, 2021). Furthermore, the opportunity to explore content through interactive and student-centered methods likely enhanced their sense of ownership and personal relevance.

In addition, the effect size analysis using Cohen's d provides further evidence of the substantial impact of the developed instructional materials. The large effect sizes observed in both the paired t-tests (d = 0.98–1.25) and independent t-tests (d = 0.80–1.15) indicate that the improvements were not only statistically significant but also practically meaningful. According to established benchmarks, values above 0.80 reflect a strong and educationally relevant influence (Kraft, 2020), suggesting that the intervention produced considerable changes in students' learning outcomes, motivation, interest, and cultural awareness. These findings imply that the instructional model did more than simply raise scores. It facilitated a deeper shift in students' engagement and understanding. This reinforces the argument that culturally responsive and interdisciplinary approaches can lead to substantial improvements in holistic learning indicators, exceeding what is typically achieved through conventional instruction (Faella et al., 2025; Walker, 2023).

Local cultural awareness also emerged as a significant factor influencing student learning. By embedding culturally familiar narratives, games, or practices into physical education lessons, the material resonated with students on a personal level, enhancing their emotional connection to the content. This approach supports culturally responsive pedagogy (Gay, 2002), which posits that teaching that is aligned with students' cultural frames of reference results in better academic outcomes (Kong et al., 2022; Lyublinskaya et al., 2024). The positive correlation and significant predictive power of local cultural

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awareness on learning outcomes in this study provide empirical backing for this pedagogical framework.

The significant correlations between motivation, interest, local cultural awareness, and learning outcomes highlight the critical role of affective and cultural dimensions in supporting academic success in physical education courses. The high correlation between motivation and learning outcomes aligns with previous studies which assert that students' intrinsic and extrinsic drives are pivotal to engagement and achievement, especially when instructional materials are perceived as meaningful and contextually relevant (Kulaksız et al., 2023; Munoto et al., 2021). The positive relationship between interest and learning outcomes suggests that students who are genuinely engaged in the learning process, particularly when the content integrates science and technology with local wisdom, are more likely to achieve better results. This confirms the importance of designing learning environments that are not only informative but also stimulating and culturally responsive.

Furthermore, the meaningful correlation between local cultural awareness and learning outcomes reflects the potential of culturally integrated pedagogy to enhance comprehension, relevance, and student identity within the learning process (Lestari & Suyanto, 2024; Sakti et al., 2024). As students recognize the local values embedded within the course content, they may develop a stronger connection with the material, thereby improving learning efficacy. This connection reinforces the idea that learning becomes more impactful when it aligns with learners' lived experiences (Conner et al., 2024). Such alignment not only enhances intellectual involvement but also fosters a personal sense of meaning and connection with the material.

The intercorrelations among the predictor variables also demonstrate that motivation, interest, and cultural awareness are interdependent factors. Motivation may act as a foundational driver that fosters both interest and cultural sensitivity, forming a reinforcing cycle that ultimately enhances students' academic outcomes (M. Liu, 2022; Quinlan et al., 2024). These results reinforce the theoretical foundations of culturally responsive teaching and suggest that future instructional designs should continue to emphasize the integration of local cultural elements to enhance both affective and cognitive domains in learning. The multiple regression results, indicating that motivation,

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interest, and local cultural awareness collectively explained 46% of the variance in learning outcomes, underscore the multifaceted nature of student achievement. No single variable dominated the learning process; rather, the synergy among affective dimensions played a pivotal role in shaping learning success. This supports the growing body of literature arguing for the inclusion of affective variables in instructional design and assessment.

In comparison to the control group, which followed conventional instructional methods, the experimental group demonstrated consistently better outcomes across all variables. This contrast affirms the added value of innovation in teaching materials, particularly when those innovations are contextually relevant and pedagogically grounded (Adam et al., 2025; Grannäs et al., 2025). Importantly, although students in the control group performed reasonably well, the absence of culturally and technologically integrated content may have limited their engagement and depth of understanding. lastly, the findings of this study hold significant implications for teacher education curricula. Preservice teachers not only benefited as learners but also gained exposure to a model of instructional practice that they can adapt and apply in their future classrooms. By experiencing firsthand the impact of culturally rooted, technology-enhanced pedagogy, these future educators are better equipped to teach in diverse and dynamic learning environments.

Although the findings of this study provide strong evidence for the effectiveness of integrating science, technology, and local wisdom into physical education instruction, several limitations should be acknowledged. First, the research was conducted within a single institutional setting, which may limit the generalizability of the results to different higher education contexts. However, it is significant to note that the institution involved serves students from various ethnic groups and diverse cultural backgrounds within the province, which delivers a rich cultural context and enhances the ecological validity of the intervention. Nonetheless, broader replication across other provinces or regions would further strengthen generalizability. Second, the post-test-only design captured immediate learning gains but did not measure long-term retention, sustained motivation, or the durability of cultural awareness over time. Third, although motivation, interest, and local cultural awareness together described a substantial proportion of the variance in learning

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outcomes, these variables do not fully capture the complexity of factors influencing learning in physical education. Additional cognitive, affective, or contextual variables may also play significant roles.

Recognizing these limitations provides meaningful direction for forthcoming research. Studies conducted across diverse institutions, including those from different cultural and demographic settings, will aid determine the robustness and adaptability of the instructional model. Longitudinal designs are also needed to study whether the observed gains persist beyond the immediate post-test period. Additionally, extending this interdisciplinary and culturally responsive approach to other courses beyond physical education may produce deeper insights into how contextualized learning materials can enhance student development across domains.

Conclusion

This study developed and evaluated interdisciplinary instructional materials for physical education that integrate scientific principles, technological tools, and local cultural wisdom. Across expert validation, small-scale trials, and large-scale implementation, the evidence constantly supports the effectiveness of the developed product. Students who engaged with the materials demonstrated significantly higher learning outcomes, motivation, interest, and cultural awareness than those in the control group, strengthening the hypotheses presented in the introduction. The findings highlight both cognitive and affective benefits of culturally integrated, technology-supported instructional design. The medium N-Gain values, significant t-test results, and large effect sizes indicate that the intervention produced meaningful, not merely statistical, improvements in learning. Furthermore, motivation, interest, and cultural awareness emerged as strong predictors of achievement, collectively explaining more than half of the variance in learning outcomes. These results underscore the importance of embedding culturally resonant and interdisciplinary elements in teacher education curricula. The study's contribution lies in offering an empirically supported model of culturally responsive physical education instruction that is adaptable to diverse learning environments. By demonstrating that the integration of science, technology, and local

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wisdom enhances both engagement and understanding, this research reinforces the value of contextualized pedagogy in preparing future elementary educators.

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