Ethno-STEM Integrated Physics Interactive Teaching Material: Its Impact to Student's Critical and Creative Thinking

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Abstract **– Developing students' learning and innovation skills, particularly critical and creative thinking, has become an essential demand of twenty-first century education. Nevertheless, evidence shows that these skills are still insufficiently fostered in conventional physics instruction, which often lacks contextual relevance and interactive engagement. To address this gap, this study introduces an Ethno-STEM Integrated Physics Interactive Teaching Material that combines cultural knowledge (ethnoscience) with the principles of science, technology, engineering, and mathematics (STEM) within an interactive learning environment. A quasi-experimental design employing a post-test-only control group was utilized. Data were collected using a test instrument administered via Google Forms. The analysis involved descriptive statistics, normality testing, hypothesis testing, and effect size testing. Findings revealed that the ethno-STEM integrated physics interactive teaching materials had a significant positive effect on students' critical and creative thinking skills. These results suggest that such materials are effective in fostering students' learning and innovation skills.**

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1. Introduction

In the 21st century, the cultivation of higher-order thinking skills, particularly critical and creative thinking, has become a central goal of science education [1], [2], [3]. These skills are essential not only for academic success but also for preparing learners to navigate complex socio-scientific issues, solve real-world problems, and participate actively in knowledge-based economies [4], [5], [6]. Physics, as a discipline, provides a powerful avenue to foster such skills because it emphasizes reasoning, problem-solving, and conceptual modeling [7]. However, conventional physics instruction often remains abstract and detached from students' lived experiences, which limits the meaningful engagement needed to develop critical and creative thinking skills.

In response to these challenges, scholars have increasingly emphasized the integration of cultural knowledge into science learning, commonly referred to as ethnoscience. Ethnoscience situates scientific concepts within culturally meaningful contexts, thereby enhancing relevance, accessibility, and engagement for students [8], [9], [10]. Embedding cultural practices, artifacts, and local wisdom in physics education can act as generative entry points for critical and creative thinking, as students connect abstract theories with tangible realities from their everyday environment [11], [12].

While ethnoscience offers contextual relevance, it often requires complementary frameworks that can channel students' engagement into structured inquiry and innovation. In this regard, the STEM has been widely recognized as a powerful pedagogical orientation to foster higher-order cognitive processes [13], [14].

STEM-based learning encourages students to explore scientific problems, apply interdisciplinary knowledge, and design solutions, thereby strengthening their abilities in reasoning, problem-solving, and creativity [15], [16]. However, without contextual grounding, STEM instruction can sometimes remain abstract and disconnected from learners' sociocultural realities, thus limiting its inclusivity and long-term impact.

This tension highlights the potential of combining both approaches. The integration of ethnoscience with STEM, commonly referred to as Ethno-STEM, has emerged as a promising direction in science education [17], [18]. Ethno-STEM seeks to unite the contextual grounding of cultural knowledge with the structured inquiry and design orientation of STEM. In physics education, such integration holds particular promise: cultural artifacts and local wisdom can serve as authentic contexts for problem-solving, while STEM processes can transform these contexts into platforms for innovation and cognitive growth [19], [20], [21].

Beyond contextual and interdisciplinary integration, the mode of instructional delivery also plays a pivotal role. Conventional teaching materials, such as static textbooks or non-interactive modules, often fall short in engaging students meaningfully or facilitating active knowledge construction. Interactive teaching materials, in contrast, can provide dynamic representations, simulations, and inquiry-based tasks that encourage exploration and reflection, thereby strengthening the pathways to higher-order thinking [22], [23], [24]. When designed with Ethno-STEM principles, such materials can bridge cultural knowledge with scientific practices in ways that are both engaging and cognitively demanding.

Despite its promise, empirical research on interactive Ethno-STEM materials in physics remains scarce. Most prior studies have either emphasized ethnoscience for fostering cultural relevance and scientific literacy, or STEM for enhancing problem-solving and creativity, but very few have systematically combined both in the design of interactive physics materials targeting critical and creative thinking. This constitutes a significant research gap.

The combination of ethno-STEM can support the use of interactive teaching materials in learning. Ethno-STEM represents an educational approach that integrates scientific concepts with local cultural knowledge [17], [18]. The integration of ethno-STEM in interactive teaching materials can improve students' learning experience [19], [20], [21]. Ethno-STEM integration not only makes learning more relevant to the cultural context, but also helps students understand science and mathematics concepts through everyday experiences.

Research shows that the application of ethno-STEM integrated physics interactive teaching material is beneficial in encouraging students' creative thinking and communication skills, as well as encouraging students to participate more actively in the educational process [16], [25]. By utilizing local culture as a learning context, students can more easily visualize the concepts taught, thereby increasing their understanding and interest in the subject matter.

Addressing this gap, the present study develops and implements Ethno-STEM integrated physics materials to promote critical and creative thinking. The research conducted has novelty from research that has been conducted by other researchers. There are several novelties in this study. First, this research combines the use of digital technology in teaching materials. Digital technology is essential for 21st-century learning. Its use can improve the quality and effectiveness of learning. Second, this study combines the integration of ethnoscience and STEM into an ethno-STEM approach within interactive teaching materials. The ethno-STEM combination is an innovative approach that can facilitate contextual learning. Third, local knowledge combined in ethno-STEM is Minangkabau culture. Minangkabau is one of the ethnic groups that inhabit the province of West Sumatra, Indonesia and has a distinctive culture. The selection of Minangkabau culture is adjusted to the background of students so that students are closer to culture in everyday life. Fourth, ethno-STEM integrated physics interactive teaching materials are designed to enhance students' learning and innovation skills. The skills enhanced are students' knowledge, critical thinking skills, and creative thinking skills. This means that not just one skill is enhanced, but three at once.

Research using ethno-STEM integrated interactive physics teaching materials in learning is important. Ethno-STEM integrated interactive physics teaching materials are an innovative solution to address learning challenges. These interactive teaching materials have various advantages that can encourage the skills needed in twenty-first century learning. The purpose of this study was to investigate the impact of implementing the ethno-STEM integrated physics interactive teaching material on students' learning skills and innovation.

2. Literature Review

Interactive teaching materials are a set of learning materials that are systematically designed so that they can create two-way interactions with students. Text, images, videos, and audio are just a few of the multimedia that enable interactive teaching materials [26], [27], [28].

The combination of various multimedia in teaching materials creates an interactive learning process [24], [28], [29]. In addition, interactive teaching materials do not only present information. However, interactive teaching materials also contain learning activities so that learning becomes interesting and enjoyable [30], [31]. By leveraging technology, interactive teaching materials are able to boost student engagement and foster the skills needed for success in the twenty-first century.

The integration of ethnoscience can facilitate the usage of interactive teaching materials. An approach of education called ethnoscience combines scientific and cultural knowledge [10], [32], [33]. The integration of ethnoscience allows students to recognize their respective regional cultures. Ethnoscience can also help develop learning that is relevant to everyday life [8], [9], [10]. In addition, the application of ethnoscience has a positive impact on learning [9], [10], [34], [35]. The integration of local culture and scientific concepts makes it easier for students to connect more with teaching materials contextually and can help students improve their understanding [32], [36]. The positive impact of ethnoscience integration in learning will support students in facing challenges in twenty-first century learning.

Interactive teaching materials can also be supported by STEM integration. The integrated STEM model is a supporter for achieving twenty-first century skills [13], [14]. A combination of two or more STEM fields – science, technology, engineering, and mathematics – is known as STEM education [37], [38], [39], [40]. One innovation in the twenty-first century education is the integration of STEM subjects. Integrating STEM into education is meant to equip students with the critical and creative thinking abilities that are essential in the twenty-first century [15], [16], [37], [41], [42]. STEM integration is also expected to produce students who have a good understanding of physics, are skilled in innovation, and are competitive in facing the development of the times. Ethno-STEM, which combines technology and culture in interactive teaching materials, has the potential to result in students who can adapt to twenty-first century learning.

Integration of ethnoscience and STEM in interactive teaching materials is important. This is because these two aspects combine local cultural knowledge with modern science [17], [25], [43]. Integration of ethnoscience and STEM (ethno-STEM) can create relevant and more meaningful learning. The combination of knowledge between local culture and modern science facilitates contextual learning through direct experience. This could improve students' abilities and motivate them to participate actively in the learning process [19], [25].

Student skills that can be facilitated through ethno-STEM integration include student knowledge, critical thinking skills, and creative thinking skills [25], [42], [44]. These abilities are a component of the learning and innovation skills that students require in the twenty-first century.

The learning and innovation skills of students are essential for twenty-first century education. Communication, teamwork, critical, and creative thinking are all components of students' learning and innovation skills [45], [46]. In addition, students' knowledge and attitudes are included in learning and innovation skills [47], [48], [49]. These abilities motivate students to fully comprehend the course materials and use them in practical situations. Furthermore, these abilities inspire students to find original and creative solutions to issues [50], [51]. Students with learning and innovation skills will be more equipped to handle the global challenges of the twenty-first century.

3. Methodology

This study examined the effectiveness of ethno-STEM integrated interactive physics teaching materials in fostering students' learning and innovation skills. The following sections detail the research design, sample selection, intervention procedures, data collection instruments, and analytical techniques used to test the research hypothesis and assess the significance of the intervention.

3.1. Research Design

This study employed a quasi-experimental method with a posttest-only control group design to examine the effectiveness of ethno-STEM integrated physics interactive teaching materials. A true experimental design was not feasible in the school context due to curricular constraints, ethical considerations, and limited classroom control. Therefore, a quasi-experimental design was chosen because it allows authentic treatments to be implemented while still maintaining control over the main variables [52]. Certain variables such as learning styles, student motivation, and student background could not be fully controlled, yet their influence was minimized through the use of cluster random sampling.

The study investigated two types of variables: the independent variable was the ethno-STEM integrated physics interactive teaching material, and the dependent variable was students' learning and innovation skills. These variables were aligned with the research objective of evaluating the extent to which the teaching material enhances higher-order learning outcomes.

While external factors such as learning styles, student motivation, parental support, and home learning environment could not be fully controlled, their potential influence was minimized through the use of cluster random sampling and the inclusion of a control group.

The research design assigned the experimental group to receive the intervention (X) and be assessed with a posttest (O_1), while the control group did not receive the intervention and was assessed with a posttest (O_2). A pretest was not administered to avoid disrupting the regular school schedule and because the primary focus of the study was to compare post-intervention outcomes. Accordingly, the experimental class was taught using ethno-STEM integrated interactive teaching materials, whereas the control class was taught using conventional material.

3.2. Sample and Population

The study population consisted of all eleventh-grade students (Phase F) of a Senior High School in West Sumatra, Indonesia (385 students across 11 classes). Samples were determined using cluster random sampling to ensure comparability across groups.

Class F-1 (36 students) was randomly assigned as the experimental group, and Class F-11 (34 students) as the control group. The students' average age ranged from 16 to 17 years. Although the sample was limited to two classes, this design reflects authentic school settings, thereby enhancing the practical relevance of the findings.

3.3. Research Procedure

The interactive teaching materials were developed through a preliminary study, expert validation, and practicality testing. Once validated, the materials were implemented in the experimental class over four sessions: three learning sessions and one posttest. The control class studied the same physics content without the interactive ethno-STEM material. The duration of treatment was constrained by the official lesson schedule, and the intervention was therefore delivered intensively within four meetings. The screenshot of the ethno-STEM integrated interactive physics teaching material is shown in Figure 1.

Figure 1. Screenshot of Ethno-STEM integrated physics interactive teaching material

3.4. Data Collection Techniques

Measurement or testing is the method of data collection Data were collected using a multiple-choice test administered via Google Forms. This type of test was selected for three main reasons: (1) Efficiency in administration and scoring; (2) High objectivity, as answers are clearly right or wrong; and (3) Suitability for measuring critical and creative thinking indicators in a quantitative manner. The test items were developed based on established indicators of critical and creative thinking skills and validated by experts before administration. Although multiple-choice tests may not fully capture open-ended reasoning, they provide high reliability and analytical clarity in large-group assessments.

3.5. Data Analysis Techniques

Data analysis included descriptive statistics (mean, standard deviation, variance), normality testing using the Lilliefors test, hypothesis testing with the Mann–Whitney U test, and calculation of effect size (Cohen's d). The Mann–Whitney U test was selected because the data did not meet the assumption of normality, making this non-parametric test more suitable. To complement statistical significance, the effect size was calculated to determine the magnitude of the intervention's impact. According to [53], a d value of 0.8 or greater indicates a large effect, values between 0.4 and 0.8 represent a medium effect, and values below 0.4 are considered small.

4. Results and Discussion

There are three ways to view the study's findings. Knowledge, critical thinking abilities, and creative thinking abilities are the three components. Test questions presented to students at the conclusion of instruction were used to gather information on their knowledge, critical thinking abilities, and creative abilities. Research findings were derived from the analysis of the collected data. The employment of ethno-STEM integrated physics interactive teaching material has an impact on students' knowledge, critical thinking, and creative thinking abilities, according to the data analysis results.

4.1. The Effect of Ethno-STEM Integrated Physics Interactive Teaching Material on Students' Knowledge

The findings demonstrate that the experimental group significantly outperformed the control group, as evidenced by higher mean, median, and mode scores, as well as a broader performance range (see. Table 1).

The Mann–Whitney U test confirmed a statistically significant difference between the two groups (U = -3.674), and the effect size (Cohen's d = 0.88) indicates a large practical impact. These results highlight the pedagogical potential of embedding cultural contexts and STEM integration within interactive physics materials to foster deeper conceptual understanding.

Table 1. Statistical analysis of student knowledge

Statistical Parameters	Experiment	Control
Average	78.78	66.35
Mode	84.00	60.00
Median	84.00	66.00
Minimum	44.00	48.00
Maximum	100.00	88.00
Range	56.00	40.00
Standard Deviation	16.42	11.40
Variance	269.55	130.053
Normality Test	Non-normal distribution	Normal
Mann-Whitney Test	-3.674	
Cohen's d Effect Size	0.88	

The performance of the experimental group can be attributed to several interrelated factors. First, the integration of ethnoscience and local cultural knowledge within STEM learning contexts has been shown to increase students' engagement and relevance perception [54], [55]. By linking abstract physics concepts to familiar cultural artifacts and problem situations, the materials may have reduced students' cognitive load and enhanced meaningful learning. Second, the interactive design of the teaching material, which combines multimedia elements with inquiry-based tasks, aligns with generative learning theory and cognitive constructivism, both of which emphasize the active role of learners in constructing knowledge [56], [57]. Moreover, the higher variance in the experimental group suggests that the intervention not only elevated overall achievement but also provided differentiated learning pathways that allowed students with diverse abilities to engage meaningfully with the material. This finding resonates with the view that culturally responsive STEM education can serve as an inclusive pedagogical approach, accommodating different learning styles and backgrounds [58].

The large effect size (d = 0.88) observed in this study is consistent with prior research reporting that culturally contextualized STEM instruction exerts substantial positive effects on student learning outcomes [59]. Importantly, this result underscores that the benefits of integrating ethnoscience into physics instruction extend beyond affective engagement to measurable improvements in cognitive outcomes.

However, the non-normal distribution of scores in the experimental group warrants further reflection. It is plausible that the novelty of the ethnoscientific context and interactive format elicited varied responses, with some students adapting quickly and excelling, while others required longer adjustment periods. This aligns with the theory of cognitive conflict in science learning, which posits that exposure to new and unfamiliar contexts can initially create disparities in performance before yielding long-term gains [60], [61].

From a broader perspective, the study provides empirical support for embedding Ethno-STEM principles into physics education to address both global and local educational challenges. On the one hand, STEM integration equips students with higher-order thinking skills and problem-solving competencies necessary for 21st-century learning [42]. On the other hand, the ethnoscientific dimension fosters cultural sustainability by validating indigenous knowledge and promoting contextualized learning. This dual contribution situates Ethno-STEM as a promising framework for reconciling global competencies with local wisdom.

Despite these promising results, some limitations should be acknowledged. The posttest-only design restricts causal inferences regarding individual learning trajectories, and the relatively small sample size may limit generalizability. Future research could adopt longitudinal or mixed-method designs to capture the dynamic processes of knowledge construction and to explore the interplay between cognitive, affective, and sociocultural dimensions of Ethno-STEM learning. Generally, the findings suggest that Ethno-STEM integrated physics interactive materials significantly enhance students' knowledge acquisition, with large effect sizes and meaningful educational implications. These results contribute to the growing body of evidence that culturally responsive STEM pedagogies are not merely supplementary but essential in creating equitable, engaging, and effective science learning environments

4.2. The Effect of Ethno-STEM Integrated Physics Interactive Teaching Material on Critical Thinking Skills

The findings demonstrate that the use of Ethno-STEM integrated physics interactive teaching materials exerts a significant influence on students' critical thinking skills (Table 2). The experimental group, which engaged with the ethno-STEM integrated materials, achieved a higher mean score compared to the control group. This difference, supported by the Mann–Whitney U test result (U = –3.674, $p < 0.05$), indicates that the intervention effectively enhanced critical thinking performance.

Table 2. Statistical analysis of critical thinking skills

Statistical Parameters	Experiment	Control
Average	79.45	68.43
Mode	86.67	86.67
Median	86.67	66.67
Minimum	40.00	33.33
Maximum	100.00	100.00
Range	60.00	66.67
Standard Deviation	17.48	16.92
Variance	305.71	286.40
Normality Test	Non-normal distribution	Normal
Mann-Whitney Test	-3.674	
Cohen's d Effect Size	0.64	

Furthermore, the calculated effect size (Cohen's d = 0.64) suggests a medium-to-large practical impact, reinforcing that the observed improvement is not only statistically significant but also educationally meaningful.

A closer examination of the distribution statistics reveals important insights. The median score of the experimental group (86.67) was markedly higher than that of the control group (66.67), suggesting that the treatment benefited the majority of students rather than only a small subset. Interestingly, while both groups shared the same mode (86.67), the control group's distribution was skewed, reflected in a wider range and the lower median. This indicates that without the ethno-STEM integrated material, students' critical thinking skills remained inconsistent, whereas the experimental group demonstrated more stable and higher-level thinking performance. The analysis of critical thinking indicators provides deeper insight into how Ethno-STEM integrated physics interactive teaching materials influence students' higher-order cognitive skills. The experimental group consistently outperformed the control group across nearly all indicators (Figure 2).

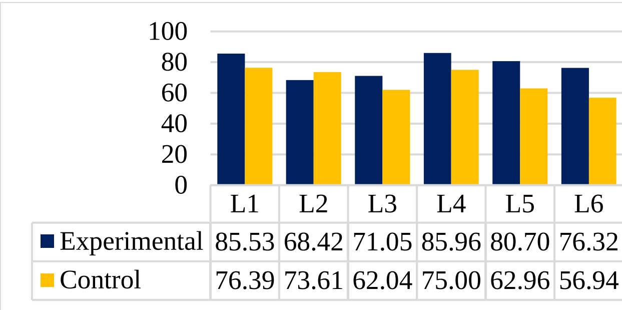

Figure 2. Critical thinking skills indicators

First, regarding the interpretation indicator (L1), the experimental group achieved an average of 85.53, which is markedly higher than that of the control group (76.39).

Interpretation involves the ability to comprehend and categorize information in a meaningful way. The superior performance in the experimental group suggests that integrating cultural contexts within STEM-based problems supported students in connecting abstract physics concepts to familiar real-world contexts. This finding aligns with situated cognition theory, which posits that learning anchored in authentic and meaningful contexts improves comprehension and transferability [62], [63].

Second, the analysis indicator (L2) reveals an interesting pattern: the control group slightly outperformed the experimental group. This anomaly may be explained by the transitional challenges students face when adapting to culturally embedded and inquiry-based materials. While such materials promote deep reasoning, some learners may initially struggle to dissect complex cultural narratives into analytical units. This observation resonates with research indicating that exposure to new pedagogical approaches can temporarily reduce performance on certain cognitive tasks before long-term gains emerge [64], [65].

Third, in terms of inference (L3), the experimental group scored 71.05 compared to 62.04 in the control group. Inference requires drawing logical conclusions from available evidence. The higher performance in the experimental group suggests that the ethno-STEM design, which embeds problem-solving in authentic contexts, encourages learners to use inductive reasoning and transfer knowledge across domains. This finding is consistent with constructivist perspectives, which emphasize that contextualized inquiry strengthens students' inferential abilities [66], [67], [68].

Fourth, evaluation (L4) emerged as the strongest indicator in both groups, with the experimental group scoring 85.96 and the control group 75.00. Evaluation entails making judgments based on criteria and standards. The large margin observed here highlights the role of interactive tasks in prompting students to critically assess data, procedures, and cultural explanations of natural phenomena. This aligns with previous studies indicating that inquiry-oriented and culturally responsive tasks foster learners' evaluative reasoning by requiring them to compare evidence, validate arguments, and reflect on alternative explanations [69], [70]. Moreover, research in science education emphasizes that evaluation is not only a cognitive process but also a metacognitive practice that helps students monitor the credibility of knowledge claims [71]. Consequently, the stronger performance of the experimental group suggests that the learning model employed was particularly effective in cultivating students' evaluative thinking as a dimension of higher-order cognition.

Fifth, explanation (L5) also showed a substantial gap (80.70 vs. 62.96). Explanation involves justifying reasoning and articulating understanding. The experimental group's advantage reflects how interactive ethnoscientific contexts demand that students not only solve problems but also explain the cultural and scientific rationale behind their answers. Prior studies have demonstrated that ethnoscience-based STEM instruction fosters dialogical reasoning and narrative articulation, which are essential for explanation skills [70], [72].

Sixth, self-regulation (L6) exhibited one of the widest disparities (76.32 vs. 56.94). Self-regulation encompasses the metacognitive processes of monitoring, reflecting, and adjusting one's reasoning. The substantial difference suggests that the experimental group benefited more from the ethno-STEM integrated design, which embedded reflective inquiry and culturally grounded problem-solving. Such integration provided authentic contexts that prompted students to evaluate not only their cognitive strategies but also the cultural relevance of their explanations. This resonates with research showing that culturally responsive tasks and inquiry-based scaffolds enhance metacognitive regulation, enabling learners to flexibly adjust their reasoning in light of both scientific evidence and sociocultural perspectives [70], [73]. Consequently, the enhanced self-regulation observed in the experimental group indicates that ethno-STEM materials can foster students' capacity to strategically monitor and refine their thinking, thereby bridging cultural knowledge with scientific reasoning.

Taken together, the indicator-level analysis reveals that Ethno-STEM integrated materials are particularly effective in strengthening interpretation, inference, evaluation, explanation, and self-regulation, while analysis requires further refinement to avoid potential cognitive overload during adaptation. Importantly, these results show that critical thinking is not a monolithic construct but a set of interdependent skills that respond differently to instructional innovations. From a broader perspective, the integration of cultural knowledge within interactive STEM materials offers dual benefits: 1) It increases students' cognitive engagement with physics concepts through contextual grounding, and 2) It fosters equity by validating indigenous knowledge systems within formal education. Thus, the present findings contribute both to the theoretical discourse on culturally responsive STEM pedagogy and to the practical development of teaching innovations aimed at 21st-century competencies.

4.3. The Effect of Ethno-STEM Integrated Physics Interactive Teaching Material on Creative Thinking Skills

The findings demonstrate that the implementation of Ethno-STEM Integrated Physics Interactive Teaching Material had a substantial positive impact on students' creative thinking skills (Table 3). The experimental group achieved a mean score of 77.78, which is significantly higher than the control group's mean score of 63.24. Moreover, the median indicates that the majority of students in the experimental group consistently performed at a higher level, suggesting that the intervention did not only benefit high-achieving students but also raised the performance baseline across the cohort.

Table 3. Statistical analysis of creative thinking skills

Statistical Parameters	Experiment	Control
Average	77.78	63.24
Mode	90.00	60.00
Median	85.00	60.00
Minimum	40.00	40.00
Maximum	100.00	90.00
Range	60.00	50.00
Standard Deviation	17.75	12.24
Variance	314.92	149.82
Normality Test	Non-normal distribution	Non-normal distribution
Mann-Whitney Test	-3.768	
Cohen's d Effect Size	0.95	

The Mann–Whitney U test result ($U = -3.768$, $p < 0.01$) confirmed a statistically significant difference between the two groups, with the effect size (Cohen's $d = 0.95$) categorized as large. This implies that the integration of ethnoscience-based contexts with STEM principles in interactive teaching materials was not merely producing small, incremental gains but rather a substantial enhancement in students' creative thinking. The greater variability observed in the experimental group ($SD = 17.75$, $Var = 314.92$) compared to the control group ($SD = 12.24$, $Var = 149.82$) further reflects that the intervention encouraged a wider spectrum of student responses, which is often a hallmark of creativity-oriented learning environments. The experimental group consistently outperformed the control group across all four indicators, confirming the statistical results that the intervention significantly improved creative thinking (Figure 3).

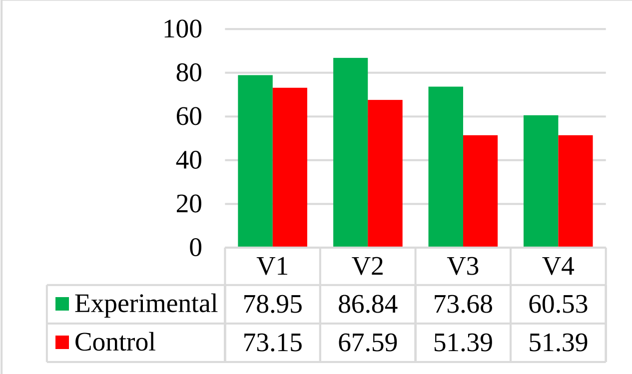

Figure 3. Creative thinking skills indicators

The improvement in fluency (V1) indicates that the integration of ethnoscientific elements broadened students' ideational repertoire. Prior research highlights that culturally grounded contexts act as generative stimuli that activate multiple cognitive entry points for problem solving, thus increasing the number of ideas students can generate [11], [12]. When combined with the systematic structure of STEM inquiry, these contexts not only encouraged divergent ideation but also ensured that ideas were subjected to logical testing and refinement. This dual process explains why students in the experimental group exhibited significantly higher fluency.

For flexibility (V2), the substantial difference between groups suggests that Ethno-STEM provided a powerful mechanism for perspective-shifting. Engaging simultaneously with cultural reasoning and scientific frameworks required learners to reinterpret problems from multiple standpoints. This resonates with studies showing that the integration of cultural practices with STEM fosters adaptive problem framing and enhances the ability to negotiate between alternative modes of reasoning [74], [75]. Such capacity to shift perspectives aligns with Guilford's conception of flexibility as the hallmark of divergent thinking.

The results on originality (V3) further strengthen the case for Ethno-STEM. Students in the experimental class produced ideas that were not only novel but also contextually meaningful. Ethnoscientific contexts exposed learners to problems outside conventional textbook formulations, pushing them toward innovative and culturally sensitive solutions. At the same time, the STEM inquiry cycle provided methodological rigor for validating these novel responses. Similar findings have been reported in cross-cultural STEM education research, where contextualized learning environments were shown to foster originality by combining cultural novelty with scientific reasoning [76].

The improvement in elaboration (V4) suggests that Ethno-STEM assisted students in refining and structuring their ideas with greater clarity and coherence. Ethnoscientific narratives served as cognitive scaffolds that anchored student reasoning in familiar and meaningful contexts. When paired with the systematic logic of STEM inquiry, these narratives facilitated more detailed and well-articulated arguments. This finding corroborates constructivist perspectives which argue that cultural and social supports play a critical role in extending students' capacity to elaborate ideas [77], [78].

The indicator-level analysis demonstrates that Ethno-STEM interactive materials particularly strengthened flexibility and originality, while also enhancing fluency and elaboration. These findings emphasize that creative thinking is a multifaceted construct, with each dimension responding differently to instructional innovations. The integration of cultural knowledge within interactive STEM materials offers dual contributions: (1) It fosters students' creative engagement with physics by situating problems in culturally meaningful contexts, and (2) It validates indigenous perspectives as legitimate resources for innovation. Hence, the present findings enrich the discourse on culturally responsive STEM pedagogy and provide empirical evidence that Ethno-STEM approaches can significantly contribute to the cultivation of 21st-century creative competencies.

Overall, the findings of this study collectively demonstrate that ethno-STEM integrated interactive physics teaching materials have a substantial impact on students' knowledge acquisition, critical thinking, and creative thinking skills. By embedding cultural elements into STEM-based physics learning, the intervention not only supports conceptual understanding but also cultivates higher-order thinking skills, which are central to 21st-century competencies. This indicates that the integration of ethnoscience and STEM principles provides a dual advantage: it contextualizes physics concepts within students' cultural backgrounds and simultaneously strengthens their cognitive engagement.

From a theoretical perspective, the study contributes to the literature by providing empirical support for the effectiveness of culturally contextualized STEM approaches in promoting knowledge mastery and higher-order thinking. It extends existing research on interactive digital learning by showing that the synergy between cultural relevance and interactivity fosters deeper learning processes. From a practical perspective, the results highlight the importance of incorporating ethno-STEM approaches into teaching practices.

Physics educators can leverage culturally grounded interactive materials to bridge the gap between abstract scientific concepts and students' lived experiences, making learning more meaningful and sustainable. Furthermore, this model has the potential to be adapted across different disciplines and educational settings to promote similar outcomes in knowledge and thinking skills.

Nevertheless, some limitations should be acknowledged, such as the relatively limited sample size and the focus on a specific cultural context, which may affect the generalizability of the findings. Future research could expand this work by involving more diverse cultural settings, longitudinal designs to track long-term effects, and comparative studies to test its scalability across various STEM domains. The study reinforces the notion that interactive, culturally integrated STEM-based teaching materials are not only effective for improving knowledge but also critical for nurturing students' critical and creative thinking, thus contributing significantly to both science education theory and classroom practice.

5. Conclusion

This study demonstrates that the integration of ethno-STEM into physics interactive teaching materials has a significant impact on students' learning outcomes. The findings reveal that such materials not only enhance students' conceptual understanding but also foster higher-order thinking skills, particularly critical and creative thinking. These improvements highlight the potential of ethno-STEM approaches to bridge scientific content with students' cultural contexts, making physics learning more meaningful and engaging. The results further suggest that ethno-STEM integrated teaching materials provide a promising pathway for equipping students with twenty-first century skills essential for problem solving, innovation, and lifelong learning. Despite these encouraging outcomes, the study is limited to the topic of heat and was conducted with a relatively narrow sample, which may constrain the generalizability of the results. Future research should extend the application of ethno-STEM interactive materials to other physics topics, incorporate broader dimensions of learning and innovation skills, and involve more diverse student populations. Such efforts will deepen understanding of how ethno-STEM can contribute to transformative learning in science education.

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