The effect of physical activity in differentiated STEAM projects on science learning and 21st-century skill development skills

El efecto de la actividad física en proyectos STEAM diferenciados en el aprendizaje de ciencias y el desarrollo de habilidades del siglo XXI

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Abstract

Objective: This study compares differentiated STEAM projects in science learning using science experiments, STEAM integration, and physical activity integration, as well as students' perceptions of the role of physical activity. This study also examines how these physical activities motivate kids and develop 21st-century abilities like teamwork, creativity, and critical thinking.
Method: This study uses mixed approaches. Students' physical activity, motivation, and 21st-century skills were assessed using a Likert scale questionnaire. Other methods include project evaluation rubrics and observation notes to objectively assess 21st-century skills and project planning document analysis for STEAM model comparison. Qualitative data was evaluated thematically, whereas quantitative data was analysed descriptively (average, standard deviation, frequency). Triangulation combined data from multiple sources.
Results: Physically active STEAM projects provide a more complete and immersive learning experience than other methods. Students liked the project's physical activities. Higher physical activity ratings correspond with improved science comprehension ($\beta = 0.68$, $R^2 \approx 0.52$). Physical activity enhances teamwork, critical thinking, and creativity ($\beta = 0.50$, $R^2 \approx 0.25$, 0.65, 0.42, 0.56, 0.33).
Conclusion: The varied STEAM project with physical activities improves student perception and scientific and 21st-century skills knowledge. Physical activity enhances learning and helps master content and skills.

Keywords

21st century skills; differentiated STEAM Project; physical activity; science learning.

Resumen

Objetivo: Este estudio compara proyectos STEAM diferenciados en el aprendizaje de ciencias mediante experimentos científicos, la integración de STEAM y la integración de la actividad física, así como las percepciones de los estudiantes sobre el papel de la actividad física. Este estudio también examina cómo estas actividades físicas motivan a los niños y desarrollan habilidades del siglo XXI como el trabajo en equipo, la creatividad y el pensamiento crítico.
Método: Este estudio utiliza enfoques mixtos. La actividad física, la motivación y las habilidades del siglo XXI de los estudiantes se evaluaron mediante un cuestionario de escala Likert. Otros métodos incluyen rúbricas de evaluación de proyectos y notas de observación para evaluar objetivamente las habilidades del siglo XXI, y el análisis de documentos de planificación de proyectos para la comparación de modelos STEAM. Los datos cualitativos se evaluaron temáticamente, mientras que los cuantitativos se analizaron descriptivamente (promedio, desviación estándar, frecuencia). La triangulación combinó datos de múltiples fuentes.
Resultados: Los proyectos STEAM físicamente activos proporcionan una experiencia de aprendizaje más completa e inmersiva que otros métodos. A los estudiantes les gustaron las actividades físicas del proyecto. Las puntuaciones más altas de actividad física se corresponden con una mejor comprensión de las ciencias ($\beta = 0{,}68$, $R^2 \approx 0{,}52$). La actividad física potencia el trabajo en equipo, el pensamiento crítico y la creatividad ($\beta = 0{,}50$, $R^2 \approx 0{,}25$, 0,65, 0,42, 0,56, 0,33).
Conclusión: El proyecto STEAM variado con actividades físicas mejora la percepción del alumnado y el conocimiento científico y de habilidades del siglo XXI. La actividad física potencia el aprendizaje y ayuda a dominar el contenido y las habilidades.

Palabras clave

Actividad física; aprendizaje de ciencias; habilidades del siglo XXI; proyecto STEAM diferenciado.

Introduction

Natural Science Learning in higher education has experienced a significant transformation, shifting from the traditional model dominated by theoretical lectures and memorizing concepts (Chattaraj et al., 2021; Shi et al., 2025). Now, the primary focus shifts to a more dynamic and applicative approach, encouraging students to not only understand "what" but also "how" and "why" scientific phenomena occur. This shift reflects the need to produce graduates who are not only rich in knowledge but also able to think critically, solve complex problems, and innovate in the face of real-world challenges (Bhuttah et al., 2024; Afzal et al., 2023). Thus, learning experiences that involve direct application become essential in the contemporary science curriculum.

The relevance of science learning to real life becomes imperative in this modern era. Scientific concepts are no longer only learned in the classroom. However, they are applied to analyze global issues such as climate change, public health, and energy sustainability (Marouli, 2021; Velempini, 2025). This transformation requires students to be actively involved in experiments, projects, and simulations that replicate the challenges of the professional world. Through this direct involvement, theoretical understanding will be internalized deeper, and students can develop the skills needed to contribute meaningfully in an increasingly complex and knowledge-based society (Al-Thani, 2025; Dong et al., 2025).

In transforming science learning, the STEAM (Science, Technology, Engineering, Arts, Mathematics) approach emerged as a relevant innovative framework. This approach inherently encourages interdisciplinary learning, breaking down traditional barriers between subjects to form a more holistic understanding (Alkhatib, 2025; Chattaraj et al., 2021). Students are invited to see how various disciplines are interrelated and can be used together to solve problems. STEAM project orientation also stimulates active learning, where students learn through designing, building, and testing solutions (Colucci et al., 2019; Makuvire et al., 2025).

The urgency of STEAM is becoming more apparent because its approach directly connects theory with real-world applications (Quigley et al., 2019). Students memorize scientific facts and use that knowledge to create products or solutions that have practical value. The involvement of the Arts aspect in STEAM is also important because it fosters creativity, imagination, and presentation skills, which are crucial in the 21st century (Leavy et al., 2023). Thus, STEAM equips students with computational, engineering, and innovative thinking skills that are much needed in various future industrial and research sectors.

In an increasingly heterogeneous higher education environment, differentiated learning becomes crucial to accommodate the diversity of students. Each individual brings a different learning style, interest, and readiness level resulting from a unique educational background and life experience (Tomlinson, 2017). A one-size-fits-all approach often fails to serve this need, potentially causing some students frustration, demotivation, and suboptimal learning outcomes (Goyibova, 2025). Therefore, a differentiation strategy is needed to ensure every student can reach their maximum academic potential, particularly for kinesthetic learners through physical activity integration.

Physical activity plays a crucial role often underestimated in learning beyond maintaining physical health. Grounded in embodied cognition theory (Novak & Schwan, 2021), physical movement activates neural pathways, strengthening connections between abstract concepts and sensorimotor experiences (Moon et al., 2022; Cardiff et al., 2023; Park, 2024). This multisensory involvement makes learning more interesting and deepens understanding and memory retention of the concepts taught (Hellison, 2025; Park, 2024). In other words, learning happens not only in the mind but also through direct interaction with the physical environment.

Moreover, physical activity is proven to affect higher cognitive functions, including problem-solving ability (Latino et al., 2024; Purnomo et al., 2024). Through hands-on experiments or simulations requiring movement, students face real challenges that encourage them to think adaptively and find innovative solutions (Javali et al., 2025; Mao et al., 2024). In addition to cognitive benefits, physical activity also contributes to students' mental and emotional well-being. Movement can reduce stress and anxiety levels, improve mood, and help students feel more energized and focused, creating a more conducive and productive learning environment as a whole (Sun et al., 2024; Al-Wardat et al., 2024; Evans et al., 2025).

Although many studies highlight the benefits of the STEAM approach, differentiated learning, and the role of physical activity separately in education, there is still a significant gap in the in-depth understanding of the synergistic integration of these three elements. The existing literature rarely examines how intentionally designed physical activities within differentiated STEAM projects impact science learning and 21st-century skill development, particularly from students' perspectives. Consequently, practitioners and curriculum developers may have difficulty designing optimal interventions.

This gap becomes more critical when we consider the perspective of students, who are the direct beneficiaries of this learning method. The lack of studies that specifically explore students' perceptions of how physical activities are integrated and impact their understanding of science concepts and 21st-century skills in differentiated STEAM projects limits our insight. Understanding from the student's point of view will provide valuable data regarding the practical effectiveness of the integration, highlighting which aspects are most beneficial or challenging. Based on the presentation of the transformation of science learning, the urgency of the STEAM approach, the importance of differentiation, as well as the crucial role of physical activity in the learning process, researchers assume that the integration of physical activity in the differentiated STEAM project can significantly improve the student's learning experience. Therefore, the primary purpose of this study is to explore and analyze in depth the perception of students towards the involvement of physical activities in implementing differentiated STEAM projects in science learning, as well as identify its impact on understanding concepts, motivation, and 21st-century skills.

Theoretical Framework

This study is anchored in constructivist learning theory (Dong et al., 2025), emphasizing knowledge construction through experience, and embodied cognition theory (Novak & Schwan, 2021), which posits that cognitive processes are deeply influenced by physical engagement. These frameworks support our hypothesis that integrating physical activity into differentiated STEAM projects enhances conceptual mastery and skill acquisition through immersive, multisensory experiences.

Research Objectives and Questions

This study aims to comprehensively examine the effectiveness of different instructional approaches in enhancing student learning outcomes and skills. Specifically, it seeks to compare students' science conceptual understanding and their 21st-century skills across three distinct approaches: conventional learning through science experiments as the control group, differentiated STEAM projects, and differentiated STEAM projects that integrate physical activity. In addition, the study explores students' perceptions regarding the role of physical activity within STEAM projects, providing insights into how such integration influences their engagement and learning experiences. Furthermore, the study measures the impact of incorporating physical activity on key components of 21st-century skills, namely collaboration, creativity, and critical thinking, to determine whether this approach offers added value in developing these competencies.

This leads to the following research questions:

1. How do learning outcomes (science conceptual understanding and 21st-century skill development) differ among science experiments, differentiated STEAM projects, and differentiated STEAM projects with integrated physical activities?
2. What are students' perceptions regarding the role and impact of physical activities in differentiated STEAM projects?
3. To what extent does physical activity within differentiated STEAM projects predict improvements in students' collaboration, creative thinking, and critical thinking skills?

Method

Research Design

This study employed a convergent parallel mixed-methods design (Creswell & Plano Clark, 2017). Quantitative data (Likert-scale surveys) and qualitative data (observations, document analysis) were collected concurrently during the 8-week intervention period. The datasets were integrated during interpretation through triangulation to: 1) Compare learning outcomes across three approaches, 2) Contextualize perception data, and 3) Explain physical activity's impact mechanisms.

This research applies a differentiated STEAM project involving physical activities in science learning to explore the impact of a differentiated STEAM project in cultivating students' 21st-century skills (cooperation, creative thinking, and critical thinking). This research combines qualitative data, especially the description of the learning process of differentiated STEAM projects involving physical activities, with quantitative data about 21st-century skills (cooperation, creative thinking, and critical thinking) of elementary school teacher candidates (Zhumabay et al., 2024).

Participants and Sampling

The sample comprised 84 third-semester elementary teacher candidates (Classes 3A=42, 3B=42) enrolled in Elementary Science. Sample size was determined using Krejcie and Morgan's formula (Tumiran, 2024) for a 150-student cohort (95% confidence level, 5% margin of error). Purposive sampling applied three criteria:

1. Enrolment in the target course
2. No prior formal STEAM project experience

Representative distribution of learning styles, identified via pre-study VARK (Visual, Auditory, Read/Write, Kinesthetic) assessment

Intervention Structure

Three sequential project phases (3 weeks each) implemented with all participants:

1. Control Phase: Traditional science experiments (e.g., chemical reactions) without STEAM or physical activity integration. In this initial phase, students engaged in traditional science experiments, such as simple chemical reactions, without the integration of STEAM elements or physical activities. This phase served as a baseline to observe learning outcomes in a conventional setting, allowing researchers to measure improvements attributable to later interventions.
2. STEAM Phase: Differentiated projects focused on content/process differentiation (e.g., "Automatic Irrigation System"). The second phase introduced differentiated STEAM projects, where students worked on tasks like developing an "Automatic Irrigation System" that emphasized both content and process differentiation. This phase aimed to foster creativity and problem-solving by encouraging students to design, build, and refine projects that connect science, technology, engineering, arts, and mathematics in meaningful ways.
3. STEAM+PA Phase: Differentiated projects with explicit physical activity integration (e.g., "Tectonic Plate Simulation"). In the final phase, students undertook differentiated STEAM projects with explicit integration of physical activities (PA), such as simulating tectonic plate movements through kinesthetic exercises in a project titled "Tectonic Plate Simulation." This approach was intended to investigate whether incorporating bodily engagement could further enhance collaboration, deepen conceptual understanding, and stimulate critical thinking beyond what was achieved in the previous phases.

Data Collection Instruments and Validation

A combination of quantitative and qualitative instruments was employed to ensure comprehensive data collection and robust validation in this study:

1. Quantitative Instruments: For the quantitative component, perception questionnaires (see Tables 1 and 2) were developed and pilot-tested with 30 students outside the participant group,

resulting in high internal consistency with Cronbach's α values ranging from 0.84 to 0.91. Content validity was further established through expert review, yielding a Content Validity Index (CVI) of 0.89 based on evaluations from three specialists in STEAM education. In addition, a 21st-Century Skills Rubric was used to assess collaboration, creativity, and critical thinking, with inter-rater reliability confirmed at $\kappa = 0.82$ through dual scoring on 20% of the collected projects, demonstrating strong agreement among evaluators.

2. Qualitative Instruments: For the qualitative component, a structured observation protocol was implemented to document the fidelity of physical activity (PA) integration and the differentiation strategies used during instruction, ensuring that the intervention aligned with the intended design (a sample of the observation protocol is provided in Appendix A). Complementing this, project artifact analysis was conducted by reviewing lesson plans, student outputs, and project documentation, applying the STEAM integration rubric adapted from Mang et al. (2023). Together, these instruments provided both breadth and depth in evaluating the intervention's implementation and its impact on student outcomes.

In order to measure the student's perception regarding the involvement of physical activities in the STEAM project with differentiation in science learning, this research will use a combination of data collection techniques, namely questionnaires and student activity sheets (Ernawati et al., 2022). This mixed-methods approach enables data triangulation, thus providing a more comprehensive and in-depth understanding. Questionnaires are used to systematically and efficiently collect quantitative data on students' general perception (Gillespie et al., 2024). The questionnaire includes students' perception of the impact of physical activity on the understanding of science concepts, as well as the development of cooperation skills, creative thinking, and critical thinking. The questionnaire will be structured using a Likert scale with five response options (1 = Strongly Disagree, 2 = Disagree, 3 = Fairly Agree, 4 = Agree, 5 = Strongly Agree). The statements in the questionnaire will refer to specific aspects of understanding the concept of science and technology and 21st-century skills integrated with physical activities in the STEAM project with differentiation in science and technology learning. The questionnaire has been validated by experts and declared valid and suitable for use. A questionnaire of students' perception of physical activity in the differentiated STEAM project in science learning is presented in Table 1.

Table 1. Questionnaire of students' perception of physical activity in STEAM project differentiation in science learning

Indicator	Statement
General Body Movement Involvement (Aubert et al., 2022., Van et al., 2021; Niklasson et al.; 2022)	I often move or change places during the science STEAM Differentiation experiment This experiment requires me to be physically active (e.g., standing, walking, bending over) I feel more energetic and not easily bored because of the physical movement in this project
Manipulation and Motor Skills (Hughes et al., 2022; Mercan et al., 2024; Zhu et al., 2023)	I use fine motor skills (such as holding a pipette, assembling small parts) actively I use gross motor skills (such as carrying equipment, organizing the work area) actively Performing physical actions helps me understand the function of tools or materials used
Understanding Concepts Through Movement	It is easier for me to understand the concept of science and STEAM integration when I involve direct physical movement Body movements help me imagine or simulate the scientific phenomenon that is being studied I feel that I can remember the lesson material better because of the physical activities I do
(Alley et al., 2023; Thoma et al., 2023; Estaiteyeh et al., 2023)	Physical activity in this experiment helps me learn in the best way that suits my learning style

Student perception questionnaire on the impact of physical activity in the differentiated STEAM project in science learning to train 21st-century skills (cooperation, creative thinking, and critical thinking) is presented in Table 2.

Table 2. Questionnaire of students' perception of the impact of physical activity in the differentiated STEAM project in science learning to train 21st century skills

Indicator	Statement
Collaboration Skills (Fizi et al., 2022; Nygren et al., 2024; Kessler et al., 2024)	I actively share roles and physical responsibilities with group members when working on projects. I feel that communication with group members becomes more effective when we do physical activities together. The group members and I help and support each other physically (for example, lifting, holding) to complete the task. I actively participate physically in solving problems or testing ideas with the group.

	This project trained me to appreciate the physical contribution of each team member.
Critical Thinking Skills (McMahon et al., 2020; Sunzuma et al., 2025; Hellison et al., 2025)	I am able to identify problems or scientific questions that arise from the physical activities I do. I think it is easier to analyze data or observation results obtained from physical activities in this project. I am able to evaluate various solutions or hypotheses by physically testing or manipulating them. I can formulate arguments or claims that are supported by strong evidence from observations and physical activity data. This project encouraged me to question assumptions and look for evidence through physical exploration. I feel that my skills in solving complex problems have improved through physical activity in this project.
Creative Thinking Skills (Creativity) (Behnamnia et al., 2025; Hayat et al., 2025)	Physical activity in this project encourages me to produce new and original ideas related to solving science problems. I am freer to experiment with unusual ways in this science project. Movement and physical manipulation help me see a scientific problem from various points of view. I can develop innovative solutions for challenges in science projects through physical exploration. This project encouraged me to combine science concepts unconventionally to create something new.

Implementation Timeline

The implementation of the intervention was organized into clearly defined phases to ensure a systematic progression of activities and data collection. Each phase was allocated a three-week period, allowing sufficient time for students to engage with the instructional approach and produce measurable outcomes. The sequence of data collection was aligned with these phases, starting with baseline assessments and continuing through post-intervention evaluations. Details of the week-by-week activities, including instructional phases and associated data collection points, are summarized in Table 3 below.

Table 3. Implementation timeline

Week	Activity
1-3	Control Phase (Science experiments) + Pre-test
4-6	STEAM Phase (Differentiated projects)
7-9	STEAM+PA Phase (PA-integrated projects)
10	Post-test + Focus groups

Differentiation Implementation

The implementation of differentiation in this study was carefully designed to address students' diverse needs, preferences, and learning styles. On the content level, students were provided with tiered readings on varying levels of ecosystem complexity. This enabled them to access material matching their prior knowledge and readiness while engaging with the same core concepts. Regarding process, multiple pathways were offered, such as kinesthetic options like body movement simulations and visual options like diagram design, allowing students to explore concepts through modalities that best suited their learning styles. For the product dimension, students were given the choice to present their final outputs either as a digital presentation or a physical prototype, thus fostering creativity and autonomy in demonstrating their understanding. The learning environment was also structured with flexible workspaces to accommodate movement-based activities, ensuring students could freely transition between individual, small-group, and whole-class tasks. This multifaceted differentiation approach was implemented to maximize engagement and deepen learning outcomes across the diverse student cohort.

Data Analysis

A comparison of differentiated STEAM projects and differentiated STEAM projects involving physical activities in science learning is obtained through literature studies, where data analysis is centered on synthesizing and interpreting information from relevant scientific sources. This research has the potential to significantly impact the field of education. Students' perception of the involvement of physical activities in the implementation of differentiated STEAM projects and the impact of physical activities in differentiated STEAM projects on science learning to foster motivation and 21st-century skills (cooperation, creative thinking, and critical thinking) of students were measured through descriptive statistical analysis of the Likert scale questionnaire. Furthermore, the quantitative and qualitative findings will be triangulated and synthesized to provide a holistic understanding of how physical activities integrated into the STEAM project with differentiation in science learning affect students' perception, motivation, and skills.

Data Analysis Procedures

The quantitative data analysis was conducted using rigorous statistical techniques to ensure valid and meaningful comparisons across the intervention phases. An Analysis of Covariance (ANCOVA) was employed to compare learning outcomes among the three phases while controlling for pre-test scores, thereby isolating the effect of each instructional approach on student performance. Furthermore, a path analysis was performed to examine the specific influence of physical activity integration on targeted 21st-century skills, with standardized β coefficients used to interpret the strength and direction of these relationships.

On the qualitative side, data were analyzed through a thematic approach using NVivo 14 software, applying a combination of deductive and inductive coding strategies. Deductive codes were derived from the research questions and theoretical framework, while inductive codes emerged from recurring patterns observed in the data. To strengthen the validity of findings, triangulation was conducted by cross-verifying regression and path analysis results with detailed observation notes, particularly focusing on collaboration patterns and interaction dynamics captured during the implementation. This integrated analytical approach provided a comprehensive understanding of both the measurable outcomes and the underlying processes that shaped students' learning experiences.

Results and Discussion

Comparison of Differentiated STEAM Projects through science experiments, STEAM integration, and integration of physical activities in science learning

Differentiated STEAM projects in science learning have developed into various models, each emphasizing how science experiments, broader STEAM elements, and physical activities are integrated to accommodate diverse learning needs. In general, various literatures show a spectrum of approaches, from those focusing on content/product differentiation with minimal physical activity to models that place physical activity as the core of the differentiated learning process. The integration of science is often the main bridge, where experiments provide an empirical basis, and physical activities offer experiential modalities. Meanwhile, STEAM elements provide dimensions for problem-solving, design, expression, and quantitative analysis. Differentiation ensures that students with a visual, auditory, or kinesthetics learning style can be optimally engaged, with physical activities very beneficial for kinesthetics learners.

This comparative analysis is based on literature synthesis rather than experimental data from this study. Table 4 shows the differences between STEAM projects and those that include physical activities in science learning. It covers how these activities fit in, the role of physical activities, the science experiments used, the strategies that stand out, and how they affect student learning and skills.

Table 4. Comparison of differentiated STEAM projects and differentiated STEAM projects involving Physical Activities in science learning

Comparative Aspects	Differentiated STEAM Projects	Differentiated STEAM Projects Involving Physical Activities
Main Focus of Integration	Emphasis on integrating Science, Technology, Engineering, Art, and Mathematics concepts through projects, with differentiation strategies on content, processes, or products. Physical activity may be present inherently (e.g., movement in the lab) but not the primary goal (Subramaniam et al., 2025; Al-Kamzari et al., 2025).	Emphasis on integrating all STEAM elements, with physical activity as a key learning modality and differentiation tool to accommodate kinesthetic/expressive learning styles.
The Role & Involvement of Physical Activity (PA)	Implicit/Minimal: Physical activity occurs naturally as part of hands-on (e.g., writing, minor assembly, clicking a mouse) but is not intentionally designed for PA learning purposes or high kinesthetic engagement (Shoshani, 2025).	Explicit & Intentional: Physical activities (gross motor, spatial exploration, body movement simulation) are actively designed and integrated as an integral part of the experiment, design, or problem-solving process to strengthen conceptual understanding and skills.

Application of science Experiments	Science experiments can be done conventionally or virtually, focusing on data collection and analysis.	Science experiments are often designed to require direct physical interaction, large-scale object manipulation, or motion simulation by students to understand phenomena.
Emphasized Differentiation Strategy	They generally focus on differentiating content (reading material, level of difficulty), process (how to do the task), and product (output format) (Ardenlid et al., 2025).	In addition to the differentiation of content, it also emphasizes the differentiation of the learning process and environment that accommodates the kinesthetic learning style, giving the option to move, build, and physically interact.
Specific Impact on Learning & Skills	Conceptual understanding, analytical skills, problem-solving, critical thinking, creativity (design).	Engagement tends to be more cognitive. Improve deep conceptual understanding (through body experience), higher learning motivation, and development of 21st-century skills (collaboration, creative thinking, critical thinking) through active physical engagement.

An example of a project done by students in the STEAM project is differentiated, for example, "Building an Automatic Irrigation System for a Mini Garden," where students design a system based on plant needs (science), use sensors (Technology), build channels (Engineering), calculate water flow (Mathematics). Differentiation: The group can choose the material (content), the assembly method (process), or the type of sensor (product). Physical activity is limited to assembly. In the differentiated STEAM project that involves physical activities, for example, "Simulation of Tectonic Plate Movement with Human Body Model," where students physically simulate the movement of plates, build an imitation model of plate movement with safe materials (Art/Engineering), record movement data (Technology), and analysed the impact (science). Differentiation is shown by students being able to choose the physical role (push, pull, slide), the type of model material, or the level of complexity of the analysed data.

The advantages of differentiated STEAM projects are to increase the relevance of learning for students by accommodating interests and learning styles, encouraging innovative thinking and more personal problem solving, and higher student involvement because there are options. In contrast, the advantages of differentiated STEAM projects that involve physical activities include high physical involvement, increasing information retention and conceptual understanding, especially for kinesthetics learners, triggering creativity and collaboration through physical interaction, and improving physical and mental health, as well as providing a very immersive and memorable learning experience. This finding lines up with some recent studies (Jesionkowska et al., 2020; Lin & Tsai, 2021; Hellison et al., 2025) that show that when you mix physical activities into a STEAM approach, it boosts students' motivation and helps them remember what they learn. This works best when it considers their likes and encourages social interaction.

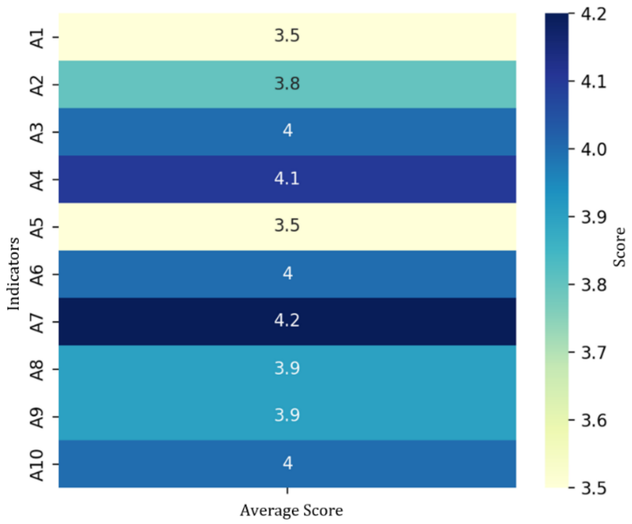
The weakness of differentiated STEAM projects is that they require more complex planning to design differentiation, require lecturers to understand the individual learning profile of students better, and implementation can be more challenging if resources or flexibility are lacking. The weaknesses of differentiated STEAM projects that involve physical activities include the need for a wide and flexible space (Thoma et al., 2023), as well as materials that may not be conventional, the potential for distraction if not managed very well, the need for lecturers who are very skilled in facilitating physical activities and relating them to scientific concepts and can be tiring or less suitable for students with certain physical conditions. A longitudinal study by Wild (2021) demonstrated that limited space and lack of teacher competence in the integration of STEAM-physical activity concepts contributed to a 40% increase in distraction incidents and decreased participation of students with disabilities compared to conventional approaches.

Students' perception of Physical Activity Involvement in Differentiated STEAM Project Implementation in Science Learning

A diagram of the perception of physical activity involvement in the implementation of the STEAM project that is differentiated is presented in Figure 1. This diagram shows how students view their involvement in physical activities during differentiated STEAM projects (that's Science, Technology, Engineering, Arts, and Mathematics). It breaks down the key factors that affect their perception, like the type and intensity of physical activities included in the projects, how much choice students get in selecting activities, and how physical activity ties into their STEAM learning goals. Feedback from teachers and classmates also plays a role.

All these factors are connected, showing that how students feel about physical activity in their learning—whether they find it fun, important, challenging, or dull—comes from how the projects are designed, how physical activities are implemented, and the overall learning environment. The goal is to boost student engagement and understanding through a more active and personalized approach to learning.

Figure 1. Perception of Physical Activity Involvement in Differentiated STEAM Project Implementation



Quantitative findings

In Figure 1, physical activities significantly increased students' science concept understanding, particularly in concretizing abstract concepts (mean score 4.3 ± 0.4 on 5-point Likert scale). Fine motor skills engagement was dominant (mean 4.1 ± 0.3), while gross motor involvement remained lower (mean 3.5 ± 0.6). Collaboration effectiveness scored 3.9 ± 0.5, though appreciation of group contributions needed improvement (3.7 ± 0.6). Critical thinking indicators showed moderate strength (mean 4.0 ± 0.4), with solution evaluation scoring highest (4.2 ± 0.3). Creativity metrics revealed challenges in unconventional experimentation (mean 3.5 ± 0.7). Thus, physical activity strengthens academic understanding and creates a dynamic and interactive learning environment. With this improvement, the STEAM project can be more optimal in equipping students with holistic 21st-century skills.

Discussion

This finding aligns with Edelsbrunner et al. (2024) regarding object manipulation enhancing memory retention. However, the lower gross motor scores suggest activity variations are needed to accommodate diverse kinesthetic learners (Arroyo-Rojas et al., 2024). Creativity constraints may stem from curriculum rigidity limiting experimental freedom (Cooper & Tang, 2024).

Although physical activity encourages critical thinking (score 4.0) through data analysis and evaluation of solutions (score 4.2), the creativity aspect is still a challenge, especially in experimenting with unconventional approaches (score 3.5). Students can formulate evidence-based arguments (score 4.1). However, innovative combining science concepts uniquely (score 3.6) needs to be stimulated more. The low exploration of unusual methods (score 3.5) shows the need for a more open project design to challenge the limits of creativity. On the other hand, collaboration skills such as helping each other (score 4.1) and problem-solving (score 4.1) have developed well, becoming the foundation for teamwork in the professional world. The implication is that educators need to design activities that involve physical activity and encourage creative risk and deep reflection. The joy in learning (score 4.4) fits with Toivo et al.

(2023) who said that physical activity releases dopamine, which helps keep kids motivated and encourages them to explore on their own. Also, the lower appreciation of team contributions (score 3.7) aligns with Newman (2020), who found that without a solid way to recognize each other, collaboration can feel unequal. To make things better, we need special strategies like creative supports tailored for different skills (Varas et al., 2023) and active peer assessments (Martinez, 2022) to balance grades and overall skills.

Student perception related to the impact of physical activity in the STEAM project with science differentiation in training students' 21st-century skills (cooperation, creative thinking, and critical thinking)

Results Section

Cooperation skills averaged high (mean 3.9/5.0 ± 0.5), while creative thinking was slightly lower (mean 3.7 ± 0.6). Critical thinking showed variability across indicators (mean 3.8 ± 0.5). Regression analysis result shown in Table 5:

Table 5. Regression analysis

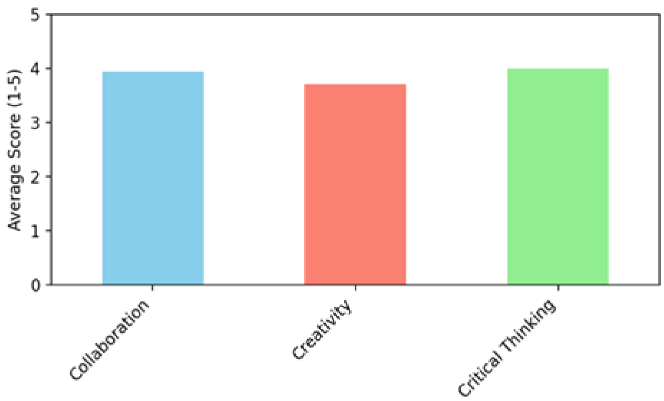
Outcome	β	R^2	P-value	95% CI
Science Understanding	0.68	0.52	<0.001	[0.61, 0.75]
Cooperation	0.50	0.25	0.003	[0.42, 0.58]
Critical Thinking	0.65	0.42	<0.001	[0.58, 0.72]
Creativity	0.56	0.33	<0.001	[0.48, 0.64]

Discussion Section

The strong association between PA and science comprehension (β=0.68, p<0.001) supports embodied cognition theories (Novak & Schwan, 2021), though the moderate R^2 values for 21st-century skills indicate additional influencing factors. Creativity's weaker linkage (R^2=0.33) suggests need for complementary interventions like risk-taking encouragement (Alves-Oliveira et al., 2022). The sample size (n=84) limits generalizability, and future studies should include control groups for causal inference.

Diagram of the perception of the impact of physical activity in the STEAM project with the differentiation of science in training 21st century skills is presented in Figure 2 below:

Figure 2. Perception of the impact of physical activity in the STEAM project differentiating science in training 21st century skills



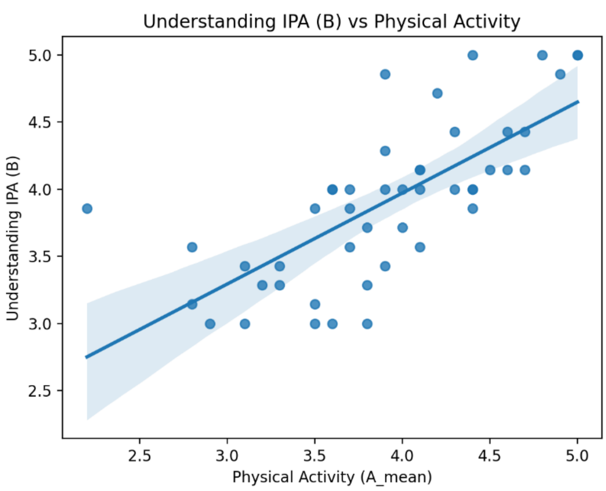
The average score of student cooperation is in the high zone, close to number 4 out of 5. This means that most students can work harmoniously, share roles, and appreciate the contribution of friends. The high value also indicates that STEAM projects that contain physical activities facilitate positive social interaction. Teams must coordinate as they move, plan, and solve problems to hone collaborative competencies naturally. However, the range of scores still leaves room for improvement. One clear solution is to assign more structured roles to ensure that each member is equally involved, which can significantly enhance the overall level of cooperation.

The aspect of creativity is balanced with cooperation but slightly lower. Students feel free to express new ideas when designing motion-based experiments or prototypes. Physical activity triggers divergent thinking—ideas emerge when the body moves, and the learning context is more contextual. However, the score difference between indicators in the heatmap shows that not all students are confident in taking creative risks. To address this, it's crucial to provide examples of creative work, as this can serve as a guide and inspiration for students, fostering a more open space for exploration and structured reflection to encourage originality.

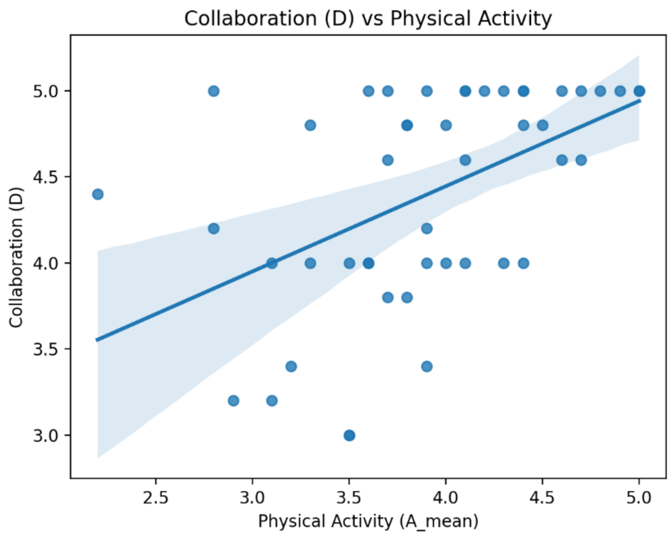
Critical thinking shows a critical score equal to or slightly below creativity. However, it is still in the good category. Students demonstrate their ability to analyze experimental data, test hypotheses, and question results logically during the project. Exposure to authentic problems and the need to adapt physical movements to science concepts seems to train their evaluative skills. However, the heatmap reveals variations; some critical indicators (e.g., the ability to formulate evidence-based arguments) are still not as high as others. Facilitators can add argumentative discussion sessions, high-level questioning scaffolding, and experimental evidence-based reflection tasks to improve this area.

The level of teamwork among students in the combined STEAM project on physical activity was pretty intense, scoring around 4 out of 5. This backs up what Valencia et al. (2021), when students work together on physical tasks, their focus improves greatly thanks to nonverbal cues and everyone playing their part. However, there is still a chance to get everyone more involved, which Lieberman et al. (2024), they suggested that having clear roles based on skills could help balance participation, especially for quieter or physically disabled students. Regarding creativity, physical activity helps spark new ideas—students scored quite high. However, their confidence in taking creative risks was lower, at 3.5. This fits with what Alves-Oliveira et al. (2022) about how lacking good examples for creative projects create a safety risk for trying bold ideas. For critical thinking, students showed a good ability to make arguments backed by evidence, scoring 4.1. This ties into what Osborne & Pimentel (2023), suggesting that students need guidance through challenging questions to strengthen reasoning skills, especially in real-world problem-solving involving movement.

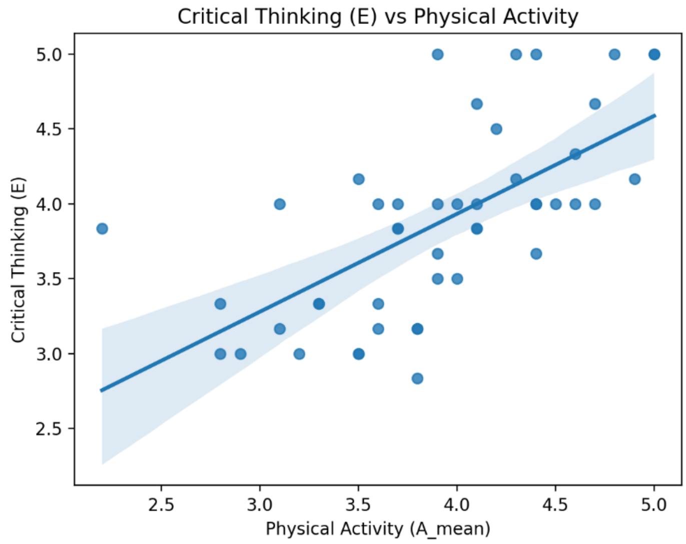
Table 6. Effect of Physical Activity on 21st Century Skills

Impact or influence	Diagram
Physical activity towards the understanding of science concepts	

Physical activity against cooperation



Physical activity against critical thinking



Physical activity against creative thinking

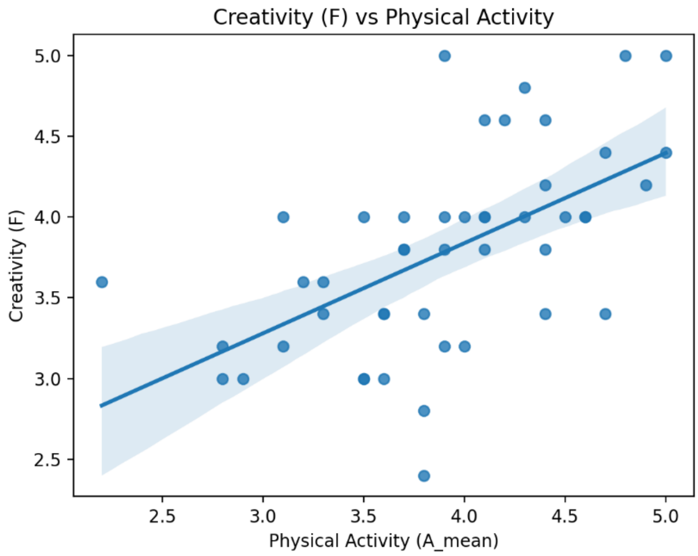


Table 6 shows (β = regression coefficient; R^2 = explained variance) with understanding of science (B): β ≈ 0.68, $R^2 \approx 0.52$, collaboration (D): β ≈ 0.50, $R^2 \approx 0.25$, critical thinking (E): β ≈ 0.65, $R^2 \approx 0.42$, creativity (F): β ≈ 0.56, $R^2 \approx 0.33$. The results show that higher physical activity (A) is consistent with a better conceptual understanding of science; more than half of the variance in Science Comprehension (B) can be explained by physical activity. This relationship remains positive for 21st-century skills (Collaboration (D), Critical Thinking (E), Creativity (F)). However, the strength is slightly weaker: approximately one-quarter to two-fifths of the variance in these skills is related to physical activity. The regression coefficients (β) are positive, underlining that more physical activity consistently predicts higher outcomes in all domains. In short, integrating physical activity appears to be a powerful lever for improving mastery of material and key skills, with the most significant impact seen on conceptual understanding

The results of this analysis back up recent findings about how physical activity can help with learning in STEAM subjects. Being active helps us grasp science concepts better, with a strong connection (about 68% of the effect) to how our brains process these ideas. This matches what Novak & Schwan (2021) found about how working with physical objects lights up parts of our brain that are crucial for understanding abstract ideas through hands-on experiences. The study highlights that physical movement plays a bigger role in developing our understanding of science and critical thinking than social skills like collaboration. Arroyo-Rojas et al. (2024) pointed out the same thing, saying that physical activity is more effective for building mental models than working together. On the other hand, creativity only shows a 33% connection to physical activity, which matches Alves-Oliveira et al. (2022), who argue that trying out new activities helps with creative thinking when paired with taking smart risks. As Zhang et al. (2020) mentioned, collaboration needs clear roles for everyone involved to make up for the fact that focusing on one factor alone does not cover everything. In short, while physical activity substantially impacts overall, improving 21st-century skills requires a mix of approaches that pair movement with effective teaching strategies tailored to specific learning goals.

Conclusions

The research shows that the Differentiated STEAM Project, which includes physical activity (PA), is a big step up from the regular differentiated STEAM project. It mixes science with STEAM elements and active movement in a more thoughtful way. This project makes body movement the main part of learning, unlike traditional methods that just sprinkle in some physical activity. Students have a really positive view of how physical activities fit into this project. They clearly see the benefits of learning through movement. In the end, the data also backs up that including physical activity in the STEAM project helps boost important 21st-century skills. It greatly helps students understand science better while also encouraging collaboration, creative thinking, and critical thinking. So, physical activity becomes a smart way to enhance learning. While results demonstrate significant benefits of PA-integrated STEAM projects (particularly for conceptual understanding), methodological constraints including sample size and absence of control conditions necessitate cautious interpretation. Physical activity serves as valuable enhancer for holistic skill development when combined with differentiated instructional design.

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