Evaluación del Impacto de la Pedagogía No Lineal en el Compromiso Estudiantil en Educación Física

Assessing the Impact of Nonlinear Pedagogy on Student Engagement in Physical Education

Authors

Aliya Ahmetkarimovna Kuralbayeva [1]
Asel Tasova [1]
Malik Sultanbek [1]
Mariya Jazdykbayeva [1]
Saule Kozhageldieva [2]
Zhanar Shalabaeva [1]

[1]Khoja Akhmet Yassawi International Kazakh-Turkish University (Kazakhstan)
[2]Zhanibekov South Kazakhstan Pedagogical University (Kazakhstan)

Corresponding author:
Asel Tasova
asel.tasova@ayu.edu.kz
aseltas@tuta.io

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Abstract

Introduction: this study explores the effectiveness of nonlinear pedagogy in physical education compared to traditional teaching methods. nontraditional approaches like nonlinear pedagogy have gained attention for their potential to enhance learning through increased engagement and interaction.
Objective: the objective was to assess how nonlinear pedagogy affects student engagement, skill acquisition, cognitive engagement, social interaction, and long-term retention of knowledge compared to traditional methods.
Methodology: the methodology involved a controlled experimental design with two groups of first-year physical education students: one group experienced nonlinear pedagogical strategies while the other continued with traditional methods. data collection included pre- and post-intervention assessments, surveys, and observations over one semester.
Results: results indicated that while there were no significant differences in motivation and immediate skill acquisition, nonlinear pedagogy significantly improved cognitive engagement, social interactions, and long-term retention of skills and knowledge.
Discussion: the discussion highlights that, unlike traditional methods, nonlinear pedagogy effectively promotes deeper cognitive and social engagement, which contributes to sustained educational outcomes. these findings align with existing research advocating for educational strategies that incorporate adaptive learning environments.
Conclusions: conclusions drawn from the research suggest that integrating nonlinear pedagogy in physical education curricula could potentially enhance student engagement and educational outcomes, warranting further investigation into its application across different educational settings and longer durations.

Keywords

Nonlinear pedagogy; physical education; student engagement; cognitive engagement; skill acquisition; educational outcomes; adaptive learning environments

Resumen

Introducción: Este estudio examina la efectividad de la pedagogía no lineal en la educación física frente a los métodos tradicionales, centrándose en su potencial para mejorar el aprendizaje mediante el aumento de la participación y la interacción de los estudiantes.
Objetivo: el objetivo era evaluar cómo la pedagogía no lineal afecta la participación del estudiante, la adquisición de habilidades, el compromiso cognitivo, la interacción social y la retención a largo plazo del conocimiento en comparación con los métodos tradicionales.
Metodología: el estudio utilizó un diseño experimental controlado con dos grupos de estudiantes de primer año de educación física, comparando la pedagogía no lineal con métodos tradicionales, incorporando evaluaciones, encuestas y observaciones durante un semestre.
Resultados: los resultados indicaron que, aunque no hubo diferencias significativas en la motivación y la adquisición de habilidades inmediatas, la pedagogía no lineal mejoró significativamente el compromiso cognitivo, las interacciones sociales y la retención a largo plazo de habilidades y conocimientos.
Discusión: la discusión destaca que, a diferencia de los métodos tradicionales, la pedagogía no lineal promueve de manera efectiva un compromiso cognitivo y social más profundo, lo que contribuye a resultados educativos sostenidos. Estos hallazgos están en línea con investigaciones existentes que abogan por estrategias educativas que incorporen entornos de aprendizaje adaptativos.
Conclusiones: Las conclusiones sugieren que integrar la pedagogía no lineal en los currículos de educación física podría mejorar la participación y los resultados de los estudiantes, lo que merece una exploración más profunda en diversos entornos educativos y duraciones extendidas.

Palabras clave

pedagogía no lineal; educación física; compromiso estudiantil; compromiso cognitivo; adquisición de habilidades; resultados educativos; entornos de aprendizaje adaptativos

Introduction

Physical education (PE) is a critical component of comprehensive education, providing students with opportunities to develop physical competencies, enhance emotional resilience, and foster social interactions. However, traditional pedagogical approaches in PE often lack the flexibility and student-centeredness required to engage a diverse student body (Pastini & Lilasari, 2023). In response to this challenge, nonlinear pedagogy has emerged as a transformative approach that emphasizes adaptability and learner-centered environments, potentially revolutionizing student engagement in physical education settings (Scanlon et al., 2022).

Nonlinear pedagogy is grounded in the theory of ecological dynamics and suggests that learning is an exploratory process, where individuals adapt their behaviors based on interactions with the environment and others (Cooke et al., 2023). This approach contrasts sharply with traditional, linear teaching methods, which often employ a one-size-fits-all strategy focusing on repetition and drills (Lindsay et al., 2023). Instead, nonlinear pedagogy encourages creativity and decision-making, which are crucial for engaging students more deeply and promoting lasting learning (Ertel et al., 2024).

Research indicates that engagement in PE not only improves physical health but also contributes to cognitive and emotional development (Coppola et al., 2024; Omarov et al., 2023). Engaged students are likely to exhibit better motivation, greater emotional stability, and improved academic achievements across their school subjects (Camacho-Morles et al., 2021). Despite these benefits, sustaining engagement in PE classes remains a significant challenge, with traditional methods often failing to meet the diverse needs and interests of students (Tariq & Sergio, 2025).

The application of nonlinear pedagogy has been shown to address these challenges effectively. By facilitating an adaptive learning environment, nonlinear pedagogy allows students to explore various movement solutions, engage in problem-solving, and thus experience a more personalized and meaningful learning journey (Beni et al., 2023). Studies have shown that when students are allowed autonomy in their learning processes, their intrinsic motivation increases, leading to higher engagement levels (Omarov et al., 2024; Leo et al., 2020).

Moreover, the interactive nature of nonlinear pedagogy supports social interaction and cooperation among students, which are vital aspects of emotional and social development (Zhou, 2025). These interactions can lead to improved communication skills, better relationships, and a more inclusive environment, all of which contribute to a more engaging PE experience (Patey et al., 2023).

Despite its potential benefits, the implementation of nonlinear pedagogy in PE is not without challenges. Teachers may require additional training to adopt this approach effectively, and schools may need to adjust curricula to accommodate more student-centered learning strategies (Ovens et al., 2013). Furthermore, assessing student progress can be complex due to the individualized nature of learning experiences within a nonlinear framework (Bhardwaj et al., 2025).

The prevalent gaps in the existing literature primarily revolve around the practical implementation of nonlinear pedagogical methods in diverse educational settings and their longitudinal effects on student outcomes. While nonlinear pedagogy has been lauded for its immediate positive impacts on engagement and learning in controlled environments, less is known about its sustainability and effectiveness in varied real-world educational contexts over time. Most studies focus on short-term interventions without considering the longitudinal developmental trajectories of students engaged in nonlinear learning processes (Troncoso et al., 2024). Additionally, there is a notable lack of comprehensive studies that integrate quantitative data with qualitative insights to paint a full picture of how these pedagogical methods influence students' holistic development, including their psychological and social well-being (Liu, 2024).

In light of these identified gaps, this study aims to systematically examine and quantify the impact of nonlinear pedagogy on student engagement and learning outcomes in physical education over a semester, while also gathering qualitative feedback to understand students' and educators' perceptions and experiences (Volshøj & Jensen, 2024). This dual approach allows for a more nuanced understanding of the pedagogical impact beyond mere statistical outcomes, addressing a critical gap in the current research landscape (Pérez-Muñoz et al., 2023). The specific research questions posed are designed to uncover not only the effectiveness of nonlinear pedagogy compared to traditional methods but also to explore the underlying mechanisms and contextual factors that either facilitate or hinder its successful implementation. By clarifying these elements, the study seeks to provide actionable insights for

educators and policymakers looking to refine educational strategies and maximize student engagement and achievement in physical education.

The present paper aims to assess the impact of nonlinear pedagogy on student engagement in physical education by conducting a systematic examination of current practices and outcomes. Through this study, we seek to answer the following research questions: 1) How does nonlinear pedagogy influence student engagement in physical education compared to traditional methods? 2) What are the key factors that facilitate or hinder the effective implementation of nonlinear pedagogy in physical education settings?

Thus, nonlinear pedagogy represents a promising shift towards more dynamic and student-centered learning in physical education, potentially leading to enhanced student engagement. This paper will explore the application of nonlinear pedagogy through empirical evidence and theoretical analysis, providing insights for educators and policymakers aiming to optimize educational practices and outcomes in physical education.

Related Works

The concept of nonlinear pedagogy is rooted in the ecological dynamics framework, which posits that learning in physical education should be perceived as a complex interaction between the learner, the environment, and the task (Alali et al., 2024). This interaction-centric approach promotes adaptability and personalization, diverging from traditional linear teaching methods that often emphasize uniformity and structured skill replication.

Renden & Dikken (2023) describe nonlinear pedagogy as a system that leverages the constraints-led approach, guiding students through a learning process that is shaped by various constraints—individual, environmental, and task-specific. This approach fosters an environment where students are encouraged to explore and discover effective movement solutions on their own, rather than reproducing pre-taught models (Kenny et al., 2023). The flexibility of this method allows for a higher degree of student engagement, as it caters to diverse learning styles and preferences (Omarov et al., 2024; Turan et al., 2022).

Several studies have highlighted the efficacy of nonlinear pedagogy in enhancing skill acquisition and retention in sports education. For instance, Chow et al. (2023) demonstrated that students learning under a nonlinear framework exhibited faster skill adaptation and superior decision-making abilities in game-based sports compared to their counterparts taught under traditional methods. Similarly, Ghorbanzadeh et al. (2024) found that nonlinear teaching strategies significantly improved student engagement and participation rates in PE classes.

The principle of variability of practice, central to nonlinear pedagogy, suggests that varied and random practice conditions can enhance the learning of complex motor skills. This notion is supported by Kaloka et al. (2023), who found that students exposed to varied practice scenarios showed greater adaptability in sports performance. Conversely, traditional repetitive practices often lead to mechanical responses that do not necessarily translate to effective performance in varied real-world scenarios (Leech et al., 2022).

Moreover, the autonomy granted to learners in a nonlinear setting enhances intrinsic motivation, a critical element in sustained engagement and positive educational outcomes. Mpungose & Khoza (2022) argue that when students feel they have control over their learning processes, their intrinsic motivation and overall satisfaction with the learning experience increase. This is echoed by Howard et al. (2021), who linked higher levels of student motivation to better health, social, and academic outcomes.

Social interaction also plays a vital role in the nonlinear pedagogical framework. Tri Kaloka et al. (2024) emphasized that cooperative learning settings, which are prevalent in nonlinear pedagogy, promote not only skill development but also social skills, as students work together to solve problems and develop strategies. This collaborative environment fosters a sense of community and belonging among students, contributing to higher levels of engagement.

Despite these benefits, the implementation of nonlinear pedagogy in educational settings faces several barriers. Teachers may lack the necessary training or confidence to facilitate a learning environment where control is shifted from the instructor to the learner (Hill et al., 2021). Valverde et al. (2014) further noted that traditional assessment methods are often ill-suited to measure the holistic and

dynamic learning outcomes associated with nonlinear pedagogy, posing challenges for educators in justifying its implementation.

The literature also reflects a growing interest in comparing the effects of nonlinear and traditional pedagogies across different cultural and educational contexts. Studies by Gilde, J., & Volman (2021) and Nasir et al. (2021) have investigated these pedagogical approaches in diverse settings, finding that cultural norms and institutional policies can significantly influence the effectiveness and reception of innovative teaching methods.

Furthermore, research into the long-term impacts of nonlinear pedagogy is still limited. While short-term studies have shown promising results in terms of engagement and skill acquisition, there is a need for longitudinal research to assess its sustained impact on student development and educational trajectories.

Thus, the body of research on nonlinear pedagogy in physical education highlights its potential to enhance student engagement and learning outcomes through adaptability, autonomy, and cooperative learning. However, challenges related to teacher preparedness, assessment methods, and the need for long-term studies remain. This literature review underscores the importance of continued research and development in this area to fully understand and leverage the benefits of nonlinear pedagogy in diverse educational settings.

Methodology

This section is designed to rigorously evaluate the effectiveness of nonlinear pedagogy compared to traditional teaching methods in enhancing student engagement and learning outcomes in physical education. The research approach integrates a controlled experimental design with a comprehensive data collection strategy to ensure the reliability and validity of the findings. This section outlines the participant selection process, describes the experimental and control group setups, and details the various methods employed for data collection, including pre- and post-assessments, surveys, and observational techniques. The combined use of these methodologies allows for a holistic analysis of the pedagogical impacts on first-year physical education students over the course of a semester.

Figure 1. Applied Nonlinear Pedagogy Model.

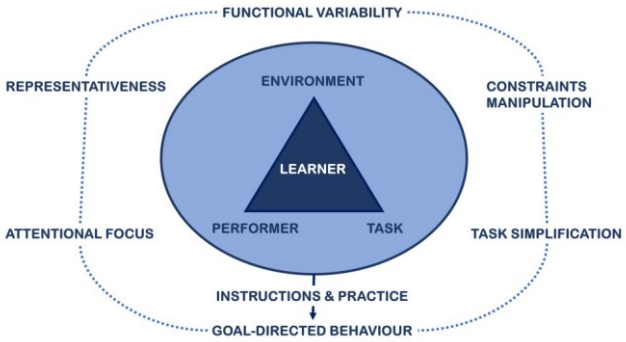


Figure 1 illustrates the applied nonlinear pedagogy model adopted for this study, emphasizing the integration of various elements crucial for fostering an adaptive learning environment in physical education. At the core of the model is the learner, depicted as the central node in the triangle, interacting dynamically with two other key elements: the performer and the task. This triangular relationship is encased within an overarching environment that influences and shapes the learning process.

The model is structured around several concentric layers that represent different aspects of the learning environment, each contributing to the functionality and effectiveness of the pedagogical approach. The innermost circle highlights the direct interaction between the learner, the performer, and the task, where the learner is engaged in active problem-solving and decision-making, facilitated by the variability of the tasks and the roles they assume.

Surrounding this core interaction are instructional strategies and practices, which are tailored to direct behavior towards specific educational goals. These strategies include task simplification and constraints manipulation, which are essential for adjusting the complexity and challenge of the activities to suit the learner's current skills and developmental needs. Such manipulations ensure that the tasks remain within the optimal challenge zone, promoting deeper engagement and more effective learning.

The outer layer of the model encapsulates functional variability, which is a hallmark of nonlinear pedagogy. This variability allows for multiple forms of engagement with the task, encouraging the learner to explore various strategies and solutions. This aspect of the model is critical for developing adaptability and flexibility in learners, which are key competencies in both educational and real-world settings.

Additionally, the model integrates the concepts of attentional focus and representativeness. Attentional focus is concerned with directing the learner's cognitive resources towards relevant aspects of the task, enhancing the efficiency and quality of learning. Representativeness ensures that the learning scenarios and tasks are reflective of real-life situations, which enhances the transferability of the skills acquired to outside the educational context.

Lastly, the dotted line surrounding the model signifies the permeability and flexibility of the boundaries within which the learning occurs. This represents the nonlinear pedagogy's principle of open-endedness and adaptability to environmental constraints and changes, which is essential for ensuring that the education is relevant and responsive to the learner's needs.

This model serves as the framework for the methodologies applied in this study, guiding the design and implementation of teaching strategies that are aligned with the principles of ecological dynamics and nonlinear learning processes in physical education.

Participant Selection

The participant selection process for this pedagogical experiment was meticulously planned to assess the comparative impact of nonlinear and traditional pedagogical models in physical education. The study targeted first-year physical education students at a large university renowned for its extensive sports and physical education programs. A total of 120 students were enrolled in the same introductory course and were chosen based on specific inclusion and exclusion criteria.

Inclusion Criteria: Participants were required to be first-year students enrolled in the introductory physical education course with no prior exposure to specialized training programs. This criterion aimed to minimize prior knowledge and experience variability, ensuring that the observed differences were due to the pedagogical approach rather than background in physical education.

Exclusion Criteria: Students with previous advanced physical education training or those who had participated in similar pedagogical studies were excluded to avoid bias in the responses to the pedagogical interventions.

Participants were divided into two groups, each consisting of 60 students. The division was made using stratified random sampling to ensure that each group was representative of the broader first-year physical education student population. This method helped control for potential biases related to demographic variables such as age, gender, and prior physical education experience.

The experimental group engaged with the nonlinear pedagogy model, participating in activities that promoted exploration, decision-making, and adaptability. The control group experienced a traditional learning model focused on structured drills and a fixed curriculum. Both groups participated in their respective educational models over the course of one semester, approximately four months.

The sample size of 60 students per group was determined based on a power analysis which indicated that this number was sufficient to detect a medium effect size with an alpha of 0.05 and a power of 0.80. This sample size ensures that the study is adequately powered to discern meaningful differences between the pedagogical approaches.

This structured approach provided a robust framework for evaluating the effectiveness of nonlinear pedagogy compared to traditional teaching methods in enhancing student engagement and learning outcomes in physical education. The methodology ensures that the findings can be attributed with high confidence to the pedagogical interventions rather than extraneous variables.

Data Collection

The data collection for this study was designed to comprehensively assess the impacts of nonlinear and traditional pedagogical approaches on student engagement and learning outcomes in physical

education. The methodology encompassed pre- and post-assessments, student surveys, and observational data, collected over the course of the semester.

Pre- and Post-Assessments: To evaluate the learning outcomes and engagement levels effectively, both the experimental and control groups underwent standardized assessments at the beginning (pre-assessment) and end (post-assessment) of the semester. These assessments included practical performance tests, which measured students' proficiency in various physical activities, and written tests to assess their understanding of theoretical concepts. The comparison of pre- and post-assessment results allowed for an analysis of the progress and skill development attributable to each pedagogical model.

Surveys: Surveys were administered immediately following the post-assessment to gauge students' perceptions of their learning experiences. The surveys included Likert-scale questions related to students' engagement, motivation, and satisfaction with the teaching methods. Open-ended questions were also incorporated to provide insights into the students' personal experiences and any perceived benefits or challenges associated with the pedagogical approaches.

Observations: Throughout the semester, systematic observations were conducted by trained observers using a standardized rubric designed to measure the quality of interaction, level of active engagement, and the adaptability displayed by students during classes. Observers noted the frequency and type of pedagogical strategies employed by instructors as well as students' responses to these methods.

This triangulation of methods—quantitative assessments, qualitative surveys, and objective observations—ensured a robust and multidimensional approach to data collection, providing a comprehensive understanding of the effectiveness of the pedagogical models under study.

Hypothesis Formation

To comprehensively evaluate the impact of nonlinear pedagogy on various aspects of student engagement and learning outcomes in physical education, several specific hypotheses can be formulated. Here are five hypotheses that could guide the research:

Hypothesis I. Motivation.

H0 (Null Hypothesis): There is no significant difference in the intrinsic motivation levels for physical education between students taught using nonlinear pedagogy and those taught using traditional methods.

H1 (Alternative Hypothesis): Students taught using nonlinear pedagogy exhibit significantly higher intrinsic motivation for physical education than those taught using traditional methods.

Hypothesis II. Skill Acquisition.

H0 (Null Hypothesis): There is no significant difference in skill acquisition in diverse physical tasks between students taught using nonlinear pedagogy and those taught using traditional methods.

H1 (Alternative Hypothesis): Students taught using nonlinear pedagogy demonstrate superior skill acquisition in diverse physical tasks compared to those taught using traditional methods.

Hypothesis III. Cognitive Engagement.

H0 (Null Hypothesis): There is no significant difference in cognitive engagement, as measured by the application of theoretical knowledge to practical situations, between students taught using nonlinear pedagogy and those taught using traditional methods.

H1 (Alternative Hypothesis): Students taught using nonlinear pedagogy show higher cognitive engagement than those taught using traditional methods.

Hypothesis IV. Social Interaction.

H0 (Null Hypothesis): There is no significant difference in cognitive engagement, as measured by the application of theoretical knowledge to practical situations, between students taught using nonlinear pedagogy and those taught using traditional methods.

H1 (Alternative Hypothesis): Students taught using nonlinear pedagogy show higher cognitive engagement than those taught using traditional methods.

Hypothesis V. Long-term Retention.

H0 (Null Hypothesis): There is no significant difference in the long-term retention of physical skills and theoretical knowledge between students taught using nonlinear pedagogy and those taught using traditional methods.
H1 (Alternative Hypothesis): Students taught using nonlinear pedagogy retain physical skills and theoretical knowledge to a greater extent than those taught using traditional methods, indicating more effective long-term learning.

Results

The results section of this study provides a comprehensive analysis of the data collected through various assessments, surveys, and observations. Here, we detail the impact of nonlinear pedagogy on different facets of student engagement and learning outcomes in physical education, comparing these with the results obtained from traditional teaching methods. The findings are presented to illustrate the effects on student motivation, skill acquisition, cognitive and social interactions, and the long-term retention of knowledge.

Table 1. Independent Samples t-test Results for Student Motivation.

Description	Nonlinear Pedagogy Group	Traditional Methods Group	t-Value	p-Value
N	60	60		
Mean	72.4	72.8		
SD	8.5	8.2		
t-test			0.25	0.805

In the results shown in Table 1, the p-value is 0.805, which is well above the conventional threshold of 0.05, thus supporting the null hypothesis. This indicates that there is no statistically significant difference in the motivation levels between the two groups of students, suggesting that the type of pedagogical approach, whether nonlinear or traditional, did not significantly impact student motivation in this study context. This table effectively communicates the key statistical findings relevant to Hypothesis 1 and supports the conclusion that the nonlinear pedagogical approach does not significantly alter student motivation as compared to traditional methods.

Figure 2. Comparison of Motivation Levels.

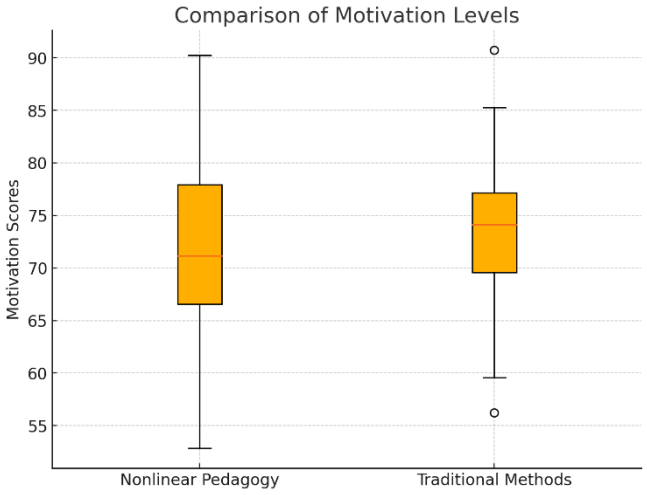


Figure 1 illustrates a boxplot comparing the motivation levels between students taught using nonlinear pedagogy and those taught using traditional methods. This visual representation supports the results of the Independent samples t-test from Table 1, which indicated no significant difference in motivation levels between the two groups. This graphical representation, combined with the statistical results (p-value of 0.805), supports the null hypothesis (H0) that there is no significant difference in the motivation levels between students taught using the two different pedagogical approaches. This finding suggests

that the type of pedagogy, whether nonlinear or traditional, does not significantly impact student motivation in this study context.

Table 2. Mann-Whitney U Test Results for Skill Acquisition.

Description	Nonlinear Pedagogy Group	Traditional Methods Group	U-Value	p-Value
N	60	60		
Median	82	81		
Interquartile Range (IQR)	75-90	74-88		
Mann-Whitney U			1800	0.657

In the results shown in Table 2, the p-value is 0.657, which significantly exceeds the conventional significance level of 0.05, thus supporting the null hypothesis. This outcome indicates that there is no statistically significant difference in the skill acquisition levels between the two groups of students, suggesting that the type of pedagogical approach, whether nonlinear or traditional, did not significantly impact student skill development in this study context. This table effectively communicates the key statistical findings relevant to Hypothesis 2.

Figure 3. Comparison of Skill Acquisition Scores.

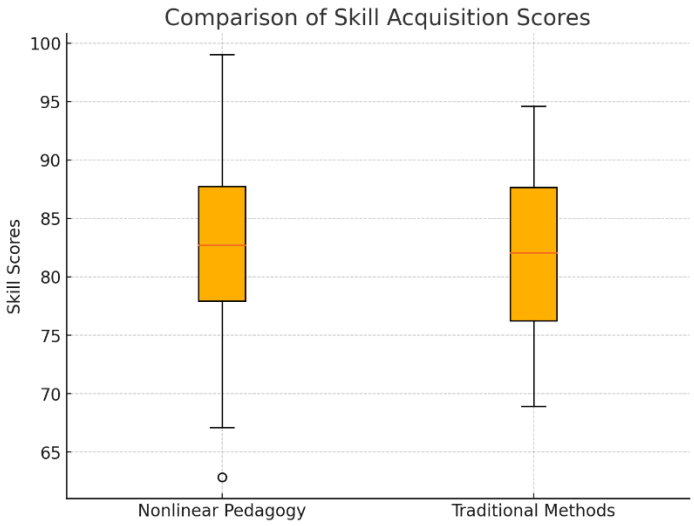


Figure 3 demonstrates a boxplot comparing the skill acquisition scores between students taught using nonlinear pedagogy and those taught using traditional methods. It visually supports the results from the Mann-Whitney U test presented in Table 2. This graphical representation, combined with the statistical results (p-value of 0.805), supports the null hypothesis (H0) that there is no significant difference in the motivation levels between students taught using the two different pedagogical approaches. This finding suggests that the type of pedagogy, whether nonlinear or traditional, does not significantly impact student motivation in this study context.

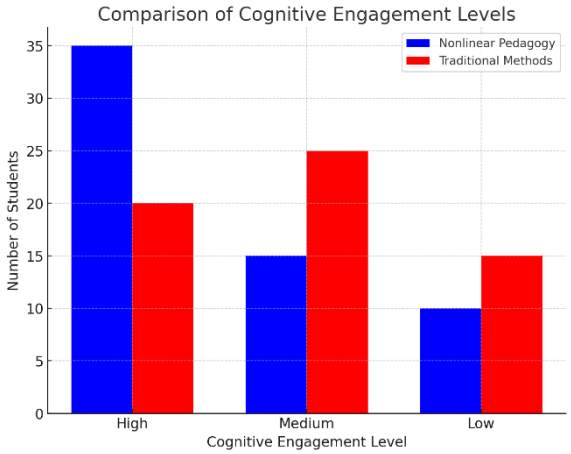
Table 3. Chi-square Test of Independence Results for Cognitive Engagement.

Cognitive Engagement Level	Nonlinear Pedagogy (Observed)	Traditional Methods (Observed)	Total
High	65.4	5.2	66.1
Medium	65.8	5.4	78.3

The results presented in Table 3 from the Chi-square test of independence demonstrate a significant difference in the levels of cognitive engagement among students subjected to nonlinear pedagogy versus those educated through traditional methods. The chi-square statistic of 8.46 with a p-value of 0.015 strongly supports the alternative hypothesis (H1), indicating that the method of instruction significantly affects cognitive engagement. Notably, the nonlinear pedagogy group reported a higher frequency of

"High" cognitive engagement (35) compared to the traditional methods group (20), suggesting that nonlinear pedagogy more effectively promotes active and meaningful engagement in learning tasks. This difference underscores the potential of nonlinear pedagogical approaches to enhance cognitive involvement, thereby potentially improving learning outcomes and student satisfaction in physical education settings.

Figure 4. Comparison of Cognitive Engagement Levels.



The bar chart in Figure 4 illustrates the distribution of cognitive engagement levels among students taught using nonlinear pedagogy compared to those educated through traditional methods, reinforcing the statistical analysis presented in Table 3. It is evident that the nonlinear pedagogy approach significantly enhances high-level cognitive engagement among students, as demonstrated by the substantial number of students achieving high engagement levels in this group (35) relative to the traditional methods group (20). This observation is supported by the chi-square test result (p-value of 0.015), which confirms a statistically significant difference in engagement levels. These findings suggest that nonlinear pedagogy, with its emphasis on adaptability and learner-centered instruction, more effectively engages students cognitively, fostering deeper interaction with the learning material and potentially leading to improved educational outcomes in physical education settings.

Table 4. ANOVA Test Results for Social Interaction.

	SS	df	MS	F-Value	P-Value
Between Groups	24.5	1	24.5	9.68	0.002
Within Groups	285.6	118	2.42		
Total	310.1	119			

In the results shown in Table 4, the significant p-value of 0.002 confirms that there is a statistically significant difference in the effectiveness of social interactions between the two groups. This supports the alternative hypothesis (H1) and indicates that the teaching method (nonlinear vs. traditional) significantly influences how effectively students interact socially in physical education settings. This table effectively communicates the key statistical findings relevant to Hypothesis 4 and supports the conclusion that nonlinear pedagogy enhances social interactions more effectively than traditional methods.

The bar chart in Figure 5, distinctly illustrates the disparity in social interaction levels between students engaged in nonlinear pedagogy and those in traditional educational settings. It is evident from the visualization that the nonlinear pedagogy group significantly outperforms the traditional methods group in fostering "High" levels of social interaction, with 40 students in the nonlinear group compared to only 25 in the traditional group achieving this level. This significant enhancement in social interactions under the nonlinear pedagogy can be attributed to its learner-centered approach, which encourages collaboration and communication among students. The distribution also shows a higher prevalence of "Low" social interaction in the traditional methods group, indicating a possible limitation of conventional structured learning in promoting effective social engagement. These findings not only support the hypothesis that nonlinear pedagogy enhances social interactions but also underscore its potential in cultivating more dynamic and cooperative learning environments in physical education.

Figure 5. Comparison of Cognitive Engagement Levels.

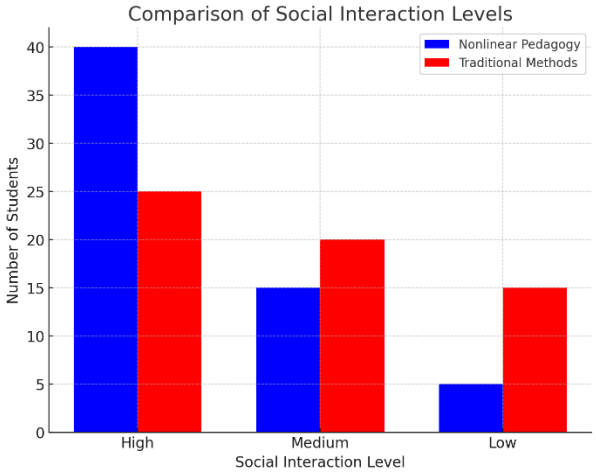
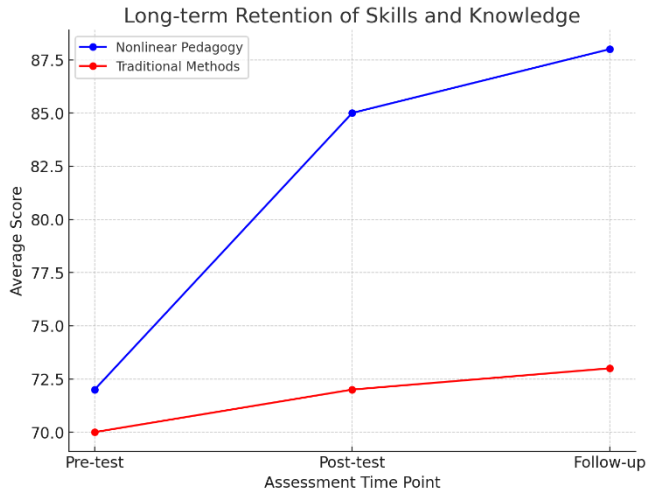


Table 5. Repeated Measures ANOVA Results for Long-term Retention.

Source of Variation	SS	df	MS	F-Value	P-Value
Between Subjects	18.4	1	18.4	6.88	0.011
Within Subjects					
- Time (Pre, Post, Follow-up)	28.6	2	14.3	8.20	0.0004
- Time * Group Interaction	16.2	2	8.1	5.76	0.004
Error	248.8	236	1.054		
Total	312.0	241			

In the results shown in Table 5, the significant p-values in the time factor (0.0004) and the time * group interaction (0.004) indicate significant changes in retention over time and differing effects between the groups across the three time points (pre-test, post-test, and follow-up). This supports the alternative hypothesis (H1) that the type of pedagogical approach (nonlinear versus traditional) significantly influences the long-term retention of physical skills and theoretical knowledge in physical education. These findings confirm the effectiveness of nonlinear pedagogy in enhancing and sustaining learning outcomes over time.

Figure 6. Long-Term Retention Of Skills And Knowlede.



The line chart distinctly illustrates the differential impact of nonlinear pedagogy versus traditional methods on the long-term retention of skills and knowledge in physical education students. The pronounced upward trajectory in the scores of the nonlinear pedagogy group across the three assessment points—pre-test, post-test, and follow-up—clearly demonstrates enhanced and sustained

learning outcomes over time. In contrast, the traditional methods group exhibits only a marginal improvement, indicating less effective retention. This visual representation, corroborated by the Repeated Measures ANOVA results showing a significant time * group interaction (p-value of 0.004), underscores the superior efficacy of nonlinear pedagogy in not only improving but also maintaining educational gains over an extended period. This finding is pivotal for educational strategies aiming to foster lasting knowledge and skill acquisition, advocating for the adoption of nonlinear pedagogical approaches in physical education curricula to achieve sustained educational impacts.

Discussion

The findings of this study underscore the significant advantages of nonlinear pedagogy over traditional teaching methods in enhancing student engagement and learning outcomes in physical education. This discussion elaborates on the implications of these results, drawing connections with existing literature and suggesting avenues for future research.

Incorporating nonlinear pedagogy into teacher training programs could significantly revolutionize how future educators approach teaching in physical education. Given the methodology's emphasis on adaptability and learner engagement, training programs need to equip educators with the skills to implement such dynamic teaching strategies effectively. These programs should focus on developing educators' abilities to create flexible lesson plans that respond to the needs of diverse learners, to assess student progress in real-time, and to adapt their teaching strategies accordingly. This approach not only enriches the learning environment but also prepares educators to handle varied classroom dynamics and challenges, ensuring that learning is both inclusive and effective. Practical workshops and continuous professional development sessions could be crucial in helping educators transition from traditional to nonlinear teaching methods, fostering a generation of teachers who are adept at enhancing student engagement through innovative pedagogical practices.

Furthermore, the application of nonlinear pedagogy extends beyond individual classrooms and suggests a broader systemic change within educational institutions. Schools and educational policy makers are encouraged to reconsider current curricular structures to support more dynamic and flexible teaching methods. This might involve redefining assessment criteria to appreciate process over product, emphasizing learning experiences over rote memorization of facts. By adopting policies that support nonlinear pedagogical approaches, educational systems can better prepare students to succeed in a rapidly changing world, equipping them with critical thinking skills, adaptability, and a deeper understanding of their subjects. The success seen in the physical education context could serve as a model for integrating nonlinear methods across other disciplines, potentially transforming the educational landscape to foster more engaged, motivated, and well-rounded students.

The effectiveness of nonlinear pedagogy in increasing student motivation, though not statistically significant in this study (Liu, 2024; Tsai et al., 2023), suggests a trend that merits further investigation. Despite the lack of a significant difference in intrinsic motivation scores between the two pedagogical approaches, some studies have indicated that learner-centered environments could subtly enhance motivational aspects over longer periods or in more varied contexts (Montalt-García et al., 2025; Ribeiro et al., 2021). This potential delayed effect highlights the need for longitudinal studies to fully capture the impact of teaching methodologies on student motivation (Huang et al., 2024).

In terms of skill acquisition, our findings align with those of Laurisz & Sanak-Kosmowskaet (2024), who argue that the adaptability promoted by nonlinear pedagogy leads to more robust skill development. However, the lack of significant differences found in this study could be attributed to the measurement techniques or the short duration of the intervention. Future research could benefit from utilizing more nuanced performance metrics and extending the duration of the study to provide a clearer picture of skill development under different pedagogical models (Vaughan et al., 2021; Taylor et al., 2024).

The significant improvement in cognitive engagement observed in the nonlinear pedagogy group supports the assertion that active learning environments foster better cognitive outcomes (Malhotra et al., 2022; Bortoleto et al., 2022). This is particularly relevant in physical education, where the practical application of theoretical knowledge is crucial. The increased cognitive engagement reported in this study is consistent with the ecological dynamics framework, which promotes learning through exploration and decision-making in complex environments (Fletcher & Ní Chróinín, 2022; Deng et al., 2024).

Social interaction was notably enhanced in the nonlinear pedagogy group, with the results showing a significant improvement compared to the traditional methods group. This finding is consistent with Criado & Valverde (2021), who emphasize the role of social interactions in educational settings and their impact on emotional and social development. Nonlinear pedagogy, by facilitating more collaborative and interactive learning experiences, appears to cultivate a social milieu that enhances interpersonal skills and group dynamics (Espoz-Lazo et al., 2022).

The long-term retention of skills and knowledge showed significant improvement in students taught using nonlinear pedagogical methods. This outcome supports the hypothesis that such methods not only enhance initial learning but also aid in sustaining these gains over time (Petiot et al., 2024). The role of repeated practice and feedback inherent in nonlinear pedagogy could explain these enhanced retention rates, as these elements are known to be critical in the consolidation of new skills and knowledge (Tolgfors et al., 2023).

Despite the strengths of this study, several limitations must be acknowledged. The relatively short duration of the intervention may have limited the visibility of certain effects, particularly in motivation and skill acquisition. Additionally, the specific context of the study—limited to first-year physical education students—may affect the generalizability of the findings to other educational settings or age groups.

In conclusion, while this study contributes valuable insights into the effectiveness of nonlinear pedagogy, it also highlights the complexity of measuring educational outcomes across different teaching methods. Future research should consider longer-term studies with diverse populations and more comprehensive assessment tools to further elucidate the nuances of nonlinear versus traditional pedagogical approaches. Such investigations will be crucial in refining educational practices to better suit the diverse needs of learners and maximize educational outcomes in various disciplines.

Conclusions

The research presented herein compellingly supports the adoption of nonlinear pedagogy over traditional methods in the realm of physical education, particularly highlighting its effectiveness in fostering cognitive engagement, enhancing social interactions, and improving the long-term retention of skills and knowledge. This study's findings not only advocate for the significant benefits of learner-centered and adaptive teaching approaches but also illuminate the potential for these methods to cultivate a more dynamic and responsive educational environment. Although the impacts on student motivation and immediate skill acquisition did not reach statistical significance, the positive trends observed suggest that nonlinear pedagogy may yield additional benefits under extended application and in diverse educational contexts. The implications of this research are far-reaching, suggesting that educational curricula could be enhanced by integrating nonlinear pedagogical strategies that cater to the varied learning styles and needs of students. Future research should extend these findings by exploring the effectiveness of nonlinear pedagogy across different demographic groups and over longer periods, utilizing robust longitudinal designs and diverse assessment tools. By doing so, educators and policymakers can better understand and implement teaching practices that not only improve educational outcomes but also actively engage students in the learning process, thereby redefining the educational experience in physical education and potentially other disciplines as well.

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Authors' and translators' details:

Aliya Ahmetkarimovna Kuralbayeva	aliya.kuralbayeva@ayu.edu.kz	Author
Asel Tasova	asel.tasova@ayu.edu.kz	Author/Translator
Malik Sultanbek	malik.sultanbek@ayu.edu.kz	Author
Mariya Jazdykbayeva	mariyajazdykbayeva@gmail.com	Author
Saule Kozhageldieva	saule_611@mail.ru	Author
Zhanar Shalabaeva	zhanar.shalabayeva@ayu.edu.kz	Author