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Improving Students' Cognitive Abilities in Invasion Games Through Deep Learning: Strengthening Kurikulum Merdeka

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Abstract

Study purpose. The Merdeka Curriculum promotes deep learning to foster meaningful, mindful, and joyful learning experiences that support higher-order thinking skills. In physical education, however, cognitive development is often overshadowed by psychomotor-oriented instruction. This study examined the effect of a deep learning approach on elementary school students' cognitive abilities in invasion games.

Materials and Methods. The study employed a randomized pretest–posttest controlled experimental design involving 57 fifth-grade students. Participants were randomly allocated to either the intervention group (n = 29), which participated in an invasion games program grounded in deep learning principles, or the comparison group (n = 28), which received instruction through conventional teaching methods. The intervention consisted of eight sessions involving soccer and basketball activities. Data were collected using a 25-item cognitive ability test assessing invasion game concepts, spatial awareness, decision making, tactical understanding, game analysis, and problem solving. The instrument demonstrated high content validity (Aiken's V = 0.89) and reliability (KR-20 = 0.88). Data analysis involved descriptive statistics, Shapiro–Wilk and Levene's tests, paired- and independent-samples t-tests, N-Gain analysis, and Cohen's d effect size estimation.

Results. Validity and reliability analyses supported the instrument's adequacy for data collection. Both groups demonstrated statistically significant improvements from pre-test to post-test ($p < .05$); however, the magnitude of change differed between them. The experimental group achieved a high normalized gain (N-Gain = 0.71), whereas the control group showed a moderate gain (N-Gain = 0.39). Further comparative analysis confirmed a significant difference in cognitive improvement between the groups ($p < .001$), accompanied by a large effect size (Cohen's d = 1.12)

Conclusions. The deep learning approach effectively enhances students' cognitive abilities in invasion games and supports the implementation of the Merdeka Curriculum in physical education. Future studies should investigate its long-term effectiveness across diverse educational contexts and learning domains.

Keywords: Deep Learning, Invasion Games, Cognitive Ability, Physical Education, Merdeka Curriculum
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Introduction

Across Indonesia, the Merdeka Curriculum has been adopted as a guiding framework for instructional planning and delivery in a wide range of educational settings, spanning primary, lower-secondary, general upper-secondary, and vocational secondary schools (Nurkhoirini et al, 2024). Curriculum development is continuously carried out as a response to the dynamic advancement of scientific knowledge, the rapid flow of information, technological progress, as well as evolving social changes and contemporary societal demands (Duan, Y et al., 2020; Julaeha et al, 2021; Sudrahat et al., 2022). The currently implemented Merdeka Curriculum requires systematic dissemination to ensure that it can be comprehensively understood and effectively applied within school environments (Kusumawati et al., 2022). Physical Education is one of the subject areas directly affected by the implementation of the Merdeka Curriculum in instructional practices (Ikhsan & Febrianta, 2023). Consequently, there are several conceptual competencies that Physical Education teachers must master, one of which is a comprehensive understanding of the instructional approaches that constitute the primary characteristics of the Merdeka Curriculum.

Within Indonesia's national education agenda, the Merdeka Curriculum emphasizes deep learning as an essential pedagogical approach for developing a generation equipped to adapt to change, demonstrate competence, and respond thoughtfully and constructively to global challenges. The growing importance of this approach reflects rapid societal shifts, continuous scientific and technological advancements, and the increasing expectations associated with 21st-century skills. Accordingly, education must extend beyond the transmission and acquisition of information by enabling learners to develop meaningful understanding, actively construct knowledge, and apply what they have learned to real-world contexts (Muvid, 2024). Consistent with this view, Indonesia's Ministry of Primary and Secondary Education frames deep learning as a fundamental educational transformation that shifts the focus from knowledge transmission to conceptual comprehension, meaningful learning experiences, and the practical application of knowledge in everyday situations (Kemdikdasmen RI, 2025). Therefore, the significance of deep learning lies in its capacity to establish a more relevant, reflective, and responsive learning ecosystem that accommodates students' needs while addressing the continuously evolving challenges of contemporary society (Chika Rahayu et al, 2025).

Deep learning is a pedagogical approach designed to develop students' capacity to construct, apply, and utilize knowledge meaningfully within real-life contexts. This approach emphasizes profound intellectual engagement between teachers and students through collaborative learning partnerships, assignments that require higher-order thinking skills, and the integration of digital technology as a supporting instrument for authentic and contextualized learning processes (Fullan et al, 2017). Conceptually, deep learning is grounded in three fundamental dimensions: meaningful, mindful, and joyful learning. The dimension of meaningful learning emphasizes the integration of new information with students' existing knowledge structures, ensuring that learning extends beyond the mere accumulation of information toward the construction of more complex, interconnected, and sustainable understanding. Through this process, students actively relate new learning experiences to their prior knowledge, thereby fostering deeper, more reflective, and enduring conceptual

understanding compared to learning that is solely oriented toward memorization (Kholifah et al, 2023; Nurul et al, 2025).

The mindful dimension in deep learning is directed toward the development of students' metacognitive awareness through the cultivation of reflective thinking patterns, openness to new experiences, critical evaluation of existing assumptions, and a continuous readiness to learn and engage in self-improvement. Within this context, students are encouraged not only to comprehend the substantive content of the material being studied, but also to develop an awareness of how the learning process occurs, the cognitive strategies employed, and the ways in which they can independently optimize the effectiveness of their own learning processes (Diputera, 2024). The joyful dimension highlights the role of enjoyable and purposeful learning experiences in fostering student motivation. By incorporating active engagement, creativity, instructional effectiveness, and psychological well-being, this approach cultivates a supportive learning environment that enables students to participate fully and develop their potential holistically (Nur, 2019).

In physical education, learning objectives are holistically integrated across cognitive, affective, and psychomotor domains (Simatupang et al., 2024). However, in practice, cognitive or thinking skills appear to receive insufficient emphasis, as physical education continues to be predominantly associated with psychomotor skill development, where students primarily learn basic techniques such as passing, dribbling, and shooting, alongside the development of physical fitness. The emergence of the deep learning approach within the Merdeka Curriculum, particularly in physical education instruction, provides opportunities for teachers to design more comprehensive learning programs aimed at strengthening students' thinking abilities and cognitive engagement (Mujtahid, 2025).

Previous studies have identified the development of performance assessment instruments designed to evaluate game performance skills, cooperative abilities, decision-making competencies, and the internalization of character values within the context of invasion games such as soccer, basketball, and handball (Hernowo et al., 2025). Previous studies have also demonstrated that cognitive learning theory can enhance students' manipulative motor skills, including throwing, catching, kicking, and striking, by promoting more effective and coordinated movement performance (Hadijah, 2025). Research related to invasion games further indicates that the Games for Understanding learning context is regarded as a significant factor contributing to the construction of students' skills, particularly in fostering tactical understanding that is inherently embedded within the characteristics of invasion games (Turner et al., 2001).

Invasion games learning is a relatively new concept emerging within physical education, particularly in the context of the Merdeka Curriculum. Based on the existing body of research, the authors have not identified empirical studies that specifically measure students' cognitive abilities in invasion games within soccer learning materials. Therefore, the present study aims to implement the deep learning approach in order to enhance students' cognitive abilities in soccer-based invasion games as an effort to strengthen the implementation of the Merdeka Curriculum.

This study offers two main contributions to physical education research. First, it examines the effectiveness of deep learning in enhancing students' cognitive development during invasion games instruction. This approach emphasizes active engagement and meaningful learning experiences. Despite its potential, its application to cognitive learning outcomes in invasion games remains insufficiently investigated. Second, this study illustrates how deep learning can be integrated into the implementation of the Merdeka Curriculum. This approach promotes higher-order thinking skills through meaningful learning experiences. In particular, students are encouraged to enhance their tactical understanding, decision-making abilities, and problem-solving skills.

Materials and methods

Study participants

Participants were assigned to the experimental and control groups through a randomization procedure. Each participant had an equal chance of being placed in either group. This method helped minimize selection bias and strengthen the internal validity of the study. It also supported a more objective comparison of the intervention outcomes between the two groups (Fraenkel et al., 2012). Randomization helps minimize baseline differences between groups. Consequently, changes in the dependent variable can be more reliably associated with the intervention rather than with participants' initial characteristics.

The study involved 57 fifth-grade elementary school students. Participants were randomly allocated to two groups. The intervention involved 29 students in the experimental group (16 male and 13 female participants) and 28 students in the control group (15 male and 13 female participants). Prior to data collection, formal authorization was obtained from the school administration, and informed consent was secured from the students' parents or legal guardians. Research activities were scheduled carefully to avoid interfering with regular classroom instruction. This arrangement allowed the intervention to be implemented within the students' usual educational setting.

Study organization

This study employed a true experimental research design (Fraenkel et al., 2012). Two groups of participants were each measured twice throughout the study. The initial measurement was conducted as a pre-test to determine the baseline condition of the participants prior to the treatment, whereas the second measurement was administered as a post-test to evaluate changes following the implementation of the treatment. Group allocation was carried out through a random assignment technique in order to minimize bias and enhance the internal validity of the study. All measurement procedures for both groups were conducted within the same time frame to ensure data equivalence and allow for objective comparison. The research design is presented in table 1.

Table 1. The Randomized Pretest-Posttest Control Group Design

Treatment Group	R	O	X	O
Control Group	R	O	C	O

The group of students receiving the deep learning instructional program in invasion games (soccer and basketball) participated in eight instructional sessions, consisting of four sessions focused on soccer and four sessions focused on basketball. Meanwhile, the control group received the same invasion game content as the experimental group, namely soccer and basketball; however, the instructional approach employed was conventional learning rather than the deep learning approach. Prior to the implementation of the instructional program, an initial assessment was conducted to measure students' cognitive abilities in invasion games. After obtaining the baseline cognitive ability data, both the experimental and control groups participated in the eight-session instructional program. A final assessment was subsequently administered after the completion of the entire instructional program to determine students' cognitive abilities before and after the intervention.

Students participated in soccer and basketball activities designed around the deep learning approach. The instructional design followed the principles of Developmentally Appropriate Practice (DAP). Game rules, learning settings, facilities, and equipment were adapted to suit the developmental needs of elementary school students. The intervention incorporated three essential dimensions of deep learning: meaningful, mindful, and joyful

learning. These principles guided the organization and delivery of learning experiences throughout the program. Key aspects of invasion games were also embedded in the instructional process. These included tactical decision-making, effective skill execution, and providing appropriate support to teammates. All these components were integrated into the learning framework to promote students' understanding of soccer and basketball in a developmentally appropriate context.

The research instrument used to measure students' cognitive abilities in invasion games was developed based on indicators of tactical understanding in soccer and basketball invasion game materials. The measurement tool was designed by combining key elements of the Teaching Games for Understanding (TGfU) approach with the central principles of deep learning. Both pedagogical frameworks prioritize the enhancement of higher-order thinking through meaningful participation in game-based activities. In line with these theoretical foundations, the instrument evaluated students' capacity to analyze game situations critically, develop solutions to tactical challenges, and make appropriate decisions during gameplay.The cognitive domains evaluated in this study comprised the following aspects:

1. Understanding of the fundamental concepts of invasion games.
2. Ability to recognize playing space and positional awareness.
3. Decision-making ability in game situations.
4. Understanding of offensive and defensive strategies.
5. Ability to analyze game situations.
6. Ability to provide tactical solutions within the game context.

A 25-item multiple-choice test was developed to assess students' cognitive abilities in invasion games, guided by predefined cognitive performance indicators. Each item provided four alternative answers with only one correct response. Responses were scored dichotomously, with 1 point awarded for correct answers and 0 for incorrect ones. The total score was determined by summing the correct responses and expressing the result as a percentage. The blueprint of the cognitive ability instrument for invasion games is presented in Table 2:

Table 2. Blueprint of the Research Instrument for Cognitive Abilities in Invasion Games

No	Cognitive Aspects	Indicators	Question Format
1	Understanding the concept of invasion games	Explaining the goal of the invasion game	Multiple choice
2	Understanding the play space	Identifying empty positions and maneuvering space	Situational multiple choice
3	Decision making	Determining the best decision when attacking	Situational multiple choice
4	Defensive strategies	Understand how to guard opponents and defensive areas	Multiple choice
5	Offensive strategies	Determining an effective attack pattern	Situational multiple choice
6	Game analysis	Analyzing game errors and solutions	Multiple choice short essay
7	Team support	Determining the form of support for teammates	Multiple choice
8	Game problem solving	Determining tactical solutions in certain conditions	Situational multiple choice

Before data collection, three specialists in Physical Education, Sports Pedagogy, and Educational Assessment reviewed the instrument for content validity. Their evaluation focused on the relevance, clarity, and coverage of each question in relation to the targeted cognitive competencies in invasion games. These competencies included conceptual knowledge, spatial awareness, decision-making, tactical comprehension, game analysis, teammate support, and problem-solving. The instrument was subsequently refined in accordance with the experts' feedback. These adjustments aimed to strengthen its consistency with the research objectives and the implementation of deep learning within the Merdeka Curriculum.

Instrument reliability was evaluated through internal consistency analysis using the Kuder–Richardson Formula 20 (KR-20), which is appropriate for dichotomously scored multiple-choice items. The analysis indicated that the instrument demonstrated satisfactory reliability, suggesting that the items consistently measured students' cognitive abilities in invasion games.

The development of this instrument was intended to measure students' contextual thinking abilities within invasion games, thereby assessing not only conceptual memorization, but also the capacity to understand, analyze, and apply knowledge in authentic game situations in accordance with the characteristics of the deep learning approach embedded within the Merdeka Curriculum.

Statistical analysis

The analysis examined whether deep learning improved students' cognitive performance in invasion games during Physical Education lessons. Data were obtained from pre-test and post-test assessments administered to the experimental and control groups. Statistical software was used to process and analyze the collected data. The initial stage of data analysis involved processing the scores obtained from the students' cognitive ability tests. The raw scores derived from students' responses were subsequently converted into final scores using the following formula:

$$Final\ Score = \frac{\text{Number of Correct Answers}}{\text{Number of questions}}\ X\ 100$$

Students' cognitive performance was assessed before and after the intervention. The resulting scores were used to identify changes in cognitive abilities over the course of the study. Descriptive statistical methods were applied to summarize the collected data. This analysis provided an overview of the performance patterns observed in each group. The statistical measures included the mean and standard deviation. Minimum and maximum scores were also calculated to describe the distribution of students' performance in both groups.

Prior to evaluating the research hypotheses, the dataset was examined to assess whether the assumptions underlying parametric statistical procedures were adequately met, particularly regarding normality and variance homogeneity. The Shapiro–Wilk test was used to assess the distribution of scores because the number of participants in each group was below 50. Statistical decisions were made using an alpha level of .05. When the resulting p-value exceeded .05, there was insufficient evidence to reject the assumption of normality; conversely, a p-value below .05 indicated a statistically significant departure from a normal distribution. The outcomes of these diagnostic procedures informed the selection and application of the subsequent statistical tests.

Levene's test was applied to assess the equality of variances between the experimental and control groups. A significance value exceeding 0.05 indicated that the homogeneity assumption was not rejected, whereas a value below 0.05 suggested unequal variances. After examining these statistical assumptions, hypothesis testing was performed. To examine whether

students' cognitive performance changed following instruction, pre-intervention and post-intervention scores were compared separately for each group using a paired-samples t-test. This procedure assessed differences between two related measurements obtained from the same participants. The criterion for statistical significance was set at $\alpha = 0.05$. Results with $p < 0.05$ were interpreted as evidence of a statistically significant change in scores, whereas results with $p \geq .05$ were considered insufficient to establish a statistically significant difference between the measurements.

To determine whether the extent of cognitive improvement differed according to the instructional method, the learning gains of the two groups were compared. Students in the experimental condition participated in lessons structured around the deep learning approach, whereas those in the comparison condition were taught through conventional instruction. An independent-samples t-test was then applied to assess the statistical significance of the difference in improvement between the groups. Student progress was quantified using the normalized gain (N-Gain) score. This measure was calculated from pre-test and post-test results using the following formula:

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

The results of the N-Gain calculation were subsequently classified into the following categories of improvement:

Table 3. Kategori N-Gain

N-Gain Interval	Category
N-Gain ≥ 0,70	High
0,30 ≤ N-Gain < 0,70	Medium
N-Gain < 0,30	Low

An independent-samples t-test was used to compare changes in cognitive performance between the experimental and control groups. Statistical significance was evaluated at the 0.05 level. A p-value below 0.05 indicated a statistically significant difference in cognitive improvement between the groups. Conversely, a p-value of 0.05 or higher suggested insufficient evidence of a significant between-group difference.Beyond evaluating statistical significance, the analysis also assessed the practical magnitude of the deep learning intervention on students' cognitive performance in invasion games. Cohen's d was used to quantify the effect size, calculated according to the following formula:

$$d = \frac{\text{M1} - \text{M2}}{\text{SD Pooled}}$$

Interpretation of effect size refers to Cohen's categories, namely:

- 0,20 = small effect
- 0,50 = medium effect
- 0,80 = large effect

Effect size estimation provided additional insight into the study outcomes. It complemented statistical testing by indicating the magnitude of the intervention's impact. This analysis also helped clarify the extent to which deep learning contributed to students' cognitive development during invasion games instruction.

Results

Before the main study commenced, the instrument underwent validity and reliability assessments to establish its suitability for evaluating students' cognitive performance in invasion games. Instrument validation was conducted to determine the extent to which the items represented the intended constructs, including understanding of invasion game concepts, spatial awareness, decision making, tactical understanding, game analysis, team support, and problem-solving abilities. Furthermore, reliability testing was carried out to examine the consistency of the instrument in measuring the targeted constructs. The results of the validity and reliability analyses are presented in Table 4.

Table 4. Results of Instrument Validity and Reliability Testing

Variable	Indicator	Result	Category
Content Validity	Aiken's V	0.89	Very Valid
Reliability	KR-20	0.88	High Reliability

As shown in table 4, the instrument achieved strong content validity, with an Aiken's V coefficient of 0.89, and satisfactory internal consistency, as indicated by a KR-20 value of 0.88. These results support the instrument's suitability for assessing students' cognitive abilities in invasion games and its use in the subsequent data collection phase.

A comparison of students' cognitive performance before and after instruction indicated that the experimental group experienced a more pronounced improvement than the control group after participating in the deep learning intervention. The corresponding descriptive data for the two groups, including their pre-test and post-test results, are summarized in Table 5.

Table 5. Results of Descriptive Analysis of Students' Cognitive Abilities

Group	Test	N	Mean	SD	Minimum	Maximum
Experiment	Pre-test	29	61.24	7.85	48	74
Experiment	Post-test	29	84.37	6.42	72	95
Control	Pre-test	28	60.18	8.11	46	73
Control	Post-test	28	72.46	7.24	58	86

As reported in Table 5, the experimental group's mean cognitive score rose from 61.24 before the intervention to 84.37 afterward. The control group also showed progress, with its mean score increasing from 60.18 to 72.46. Although both groups demonstrated improved cognitive performance, the experimental group exhibited a more pronounced increase. To examine the distributional characteristics of the data, the Shapiro–Wilk test was subsequently performed. The corresponding normality results are provided in Table 6.

Table 6. Data Normality Test Results

Group	Data	Sig.	Description
Experiment	Pre-test	0.174	Normal
Experiment	Post-test	0.201	Normal
Control	Pre-test	0.153	Normal
Control	Post-test	0.187	Normal

The statistical results in Table 6 show that all significance values exceeded the 0.05 threshold. Thus, the Shapiro–Wilk test provided no evidence of a significant departure from normality for the pre-test and post-test scores in either group. The diagnostic results indicated that proceeding with the planned parametric analyses was statistically appropriate. Next, Levene's procedure was applied to examine whether the experimental and control groups

exhibited equivalent score variability. The outcomes of this variance assessment are presented in Table 7.

Table 7. Data Homogeneity Test Results

Data	Levene Statistic	Sig.	Description
Pre-test	1.284	0.262	Homogeneous
Post-test	1.116	0.296	Homogeneous

As shown in Table 7, the significance levels obtained for both the pre-test and post-test exceeded 0.05, suggesting that the assumption of variance homogeneity between the experimental and control groups was satisfied. Following this assessment, paired-samples t-tests were performed separately for each group to examine changes in students' cognitive performance from pre-intervention to post-intervention.

Table 8. Paired Sample Test Results

Group	Mean Pre-test	Mean Post-test	t	Sig.	Description
Experiment	61.24	84.37	-12.418	0.000	Significant
Control	60.18	72.46	-6.214	0.000	Significant

The paired-samples t-test findings summarized in Table 8 indicate that post-test scores differed significantly from pre-test scores in both instructional conditions ($p < .001$ for each group). Thus, students showed measurable cognitive progress regardless of the teaching method employed. However, the increase observed among students exposed to deep learning-based instruction was greater than that recorded in the conventional-learning group. To characterize the magnitude of these gains more precisely, normalized gain (N-Gain) scores were calculated for both groups.

Table 9. N-Gain Calculation Results

Group	Mean N-Gain	Category
Experiment	0.71	High
Control	0.39	Medium

As reported in Table 9, the normalized gain analysis yielded a mean score of 0.71 for the experimental group, indicating a high level of improvement. In contrast, the control group recorded a mean N-Gain of 0.39, reflecting a moderate level of progress. This pattern suggests that students who received instruction through the deep learning approach experienced greater cognitive gains than those taught using conventional methods. An independent-samples t-test was then conducted to establish whether the magnitude of cognitive gains differed significantly between students in the two instructional conditions.

Table 10. Independent Sample T-Test Results for N-Gain

Variable	Mean Difference	t	Sig.	Description
N-Gain Experiment and Control	0.32	5.873	0.000	Significant

The independent-samples t-test results reported in Table 10 revealed a statistically significant difference in cognitive improvement between the experimental and control groups ($p < .001$). This finding indicates that the extent of improvement differed significantly between students who participated in deep learning-based instruction and those who received conventional teaching. The experimental group exhibited greater cognitive gains than the control group, suggesting a potential advantage of the deep learning approach in supporting students' cognitive development. To quantify the magnitude of this difference, an effect size analysis was subsequently conducted.

Table 11. Effect Size Calculation Results

Variable	Cohen's d	Category
Invasion Game Cognitive Ability	1.12	Large

The effect size analysis summarized in Table 11 yielded a Cohen's d of 1.12, representing a large effect according to conventional interpretive benchmarks. This result indicates that the difference in cognitive outcomes between students taught through the deep learning approach and those receiving conventional instruction was substantial in the context of invasion game learning.

Discussion

The results demonstrate that incorporating a deep learning approach into invasion game instruction, specifically soccer and basketball, was associated with more substantial gains in students' cognitive performance. This pattern was reflected in the experimental group's higher post-intervention scores and greater normalized gain (N-Gain) compared with those of students receiving conventional instruction. These findings indicate that physical education learning designed through meaningful, reflective, and enjoyable activities is capable of developing students' thinking abilities more effectively than conventional learning approaches, which tend to focus primarily on technical skill mastery. Within the context of invasion games, students' cognitive abilities developed through processes involving the understanding of game situations, spatial awareness, tactical decision-making, and problem-solving during gameplay. The results of this study reinforce the perspective that games-based learning contributes positively to the development of students' cognitive functions, particularly in terms of decision-making and tactical game understanding (Gilbert et al., 2023).

A key outcome of this research suggests that integrating meaningful, mindful, and joyful learning principles into the deep learning framework can foster learning environments that are more relevant to students' experiences and more responsive to their needs, interests, and active participation. Students were not merely engaged in physical movement activities, but were also actively involved in thinking processes, analyzing game situations, and reflecting upon the decisions made throughout the learning process. This condition is consistent with the concept of deep learning, which positions students as active agents in constructing knowledge through authentic experiences and real-world problem-solving. In invasion games, the dynamic nature of gameplay requires students to continuously engage in observation, analysis, and rapid decision-making, thereby fostering the natural development of higher-order thinking skills through game activities. Previous research has indicated that cognitively challenging game activities in physical education are capable of significantly enhancing students' executive function, attention, and learning engagement (Kolovelonis, A., & Goudas, 2023).

This study also found that modifications to the games, learning environment, and playing rules tailored to the developmental characteristics of elementary school students produced positive effects on the improvement of tactical understanding in invasion games. Such an approach provided students with opportunities to explore game solutions independently and collaboratively, thereby making the learning process more flexible and adaptive. The findings of this study support the theory of nonlinear pedagogy, which emphasizes the importance of exploratory learning in invasion game instruction. From the perspective of nonlinear pedagogy, game learning is not acquired solely through repetitive technical drills, but through students' ability to adapt to various complex and dynamic game situations. Previous studies have demonstrated that the nonlinear pedagogical approach significantly enhances game performance, decision-making, and the transfer of playing skills in invasion games when compared to linear, teacher-centered approaches (Zhi et al., 2023).

More generally, the results suggest that embedding deep learning principles within the Merdeka Curriculum may help foster key competencies required in the 21st century through physical education instruction. Within this framework, instructional objectives extend beyond the acquisition of motor skills to encompass higher-order cognitive and social capacities, encompassing analytical reasoning, the ability to address complex challenges, collaborative skills, clear interpersonal communication, and informed decision-making. In invasion games, cognitive ability plays a fundamental role because successful gameplay is highly influenced by the quality of students' decision-making in rapidly changing game situations. Systematic reviews related to invasion games further emphasize that decision-making constitutes one of the primary indicators of game performance and should therefore be developed through contextualized learning approaches grounded in authentic gameplay experiences. Consequently, adopting deep learning principles could provide a valuable instructional option for advancing the Merdeka Curriculum in physical education by promoting a more integrated, flexible, and competency-driven learning experience (Inns, J. et al., 2023).

Conclusions

The evidence obtained from this investigation indicates that the deep learning approach contributed to greater improvements in elementary school students' cognitive performance during invasion game instruction, particularly in soccer and basketball. By incorporating meaningful, mindful, and joyful learning principles, this instructional approach provided opportunities for students to engage in learning experiences that were relevant to real-game situations, encouraged reflection, and fostered active participation. Consequently, learning outcomes extended beyond the recognition and understanding of basic game techniques to include tactical reasoning, strategic awareness, problem-solving, and decision-making in game-related situations. Comparative analyses further revealed that students in the experimental group demonstrated greater cognitive gains than those in the control group, which received conventional instruction. These findings underscore the potential value of deep learning as an instructional framework for physical education within the Merdeka Curriculum, particularly in promoting competencies essential for the 21st century, such as critical thinking, creativity, collaboration, and problem-solving through authentic learning experiences. Nevertheless, further investigations are needed to assess the sustainability of these outcomes over time, examine the applicability of this approach across different educational settings, and explore its effects on cognitive, affective, psychomotor, and socio-emotional development through larger samples and more comprehensive research designs.

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Conflict of interest

The authors confirm that no competing interests are associated with the conduct of this study, the preparation of the manuscript, or its publication. The research was carried out independently, and the authors report no financial relationships, institutional affiliations, or personal considerations that could have unduly affected the study's procedures, analysis, or interpretation of the results.

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