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Article

A Comparative Study Between Creative Thinking and Critical Thinking and Their Application in Physics Education

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Abstract

This study investigates the comparative impact of creative thinking and critical thinking instruction in high school physics education. A quasi-experimental quantitative design was employed involving 94 students from Grades 10 and 12 in the United Arab Emirates. Participants were divided into two groups: one received physics instruction emphasizing creative thinking, while the other focused on critical thinking strategies. Pre- and post-tests were administered using adapted versions of the Torrance Tests of Creative Thinking (TTCT) and the Watson–Glaser Critical Thinking Appraisal (WGCTA). The findings revealed significant gains in both groups; however, students in the creative thinking group showed greater improvement, particularly in fluency, flexibility, and originality. Younger students (Grade 10) demonstrated higher responsiveness to creative instruction, whereas gender had no significant effect. These results highlight the value of integrating creative pedagogy into physics education and suggest that fostering divergent thinking can promote deeper conceptual understanding and enhance innovation readiness among science learners.

Keywords: Creative thinking, critical thinking, physics education, convergent thinking, divergent

INTRODUCTION

Creative and critical thinking are widely recognized as cornerstones of 21st-century education. These cognitive abilities are essential for enabling learners to adapt to complex, real-world problems, particularly in scientific disciplines such as physics. Creative thinking involves the capacity to generate original ideas, explore new perspectives, and propose imaginative solutions. In contrast, critical thinking is rooted in reasoning, evaluation, and logical analysis. Physics, as a subject that demands conceptual understanding, application, and innovation, provides a rich platform for cultivating both thinking styles.

Despite the acknowledged importance of these skills, limited empirical research has directly compared the effectiveness of creative and critical thinking strategies in physics education. This study addresses that gap by examining how each thinking style influences students' learning outcomes, problem-solving abilities, and engagement with physics content.

Critical thinking is a cognitive pattern that learners must acquire. It involves the use of reasoning skills to analyze ideas, evaluate arguments, and solve problems systematically, ultimately improving learning outcomes [1]. Creative thinking, a fundamental 21st-century skill, is equally vital for human development and serves as a catalyst for innovation. It encourages learners to analyze, synthesize, and evaluate information from multiple perspectives—an ability crucial for making informed decisions and addressing complex problems [2].

The optimization of higher-order thinking skills, including both creative and critical thinking, is essential in modern education, as these are life skills necessary for navigating contemporary challenges [3]. Creative thinking, in particular, entails seeking solutions, formulating and testing hypotheses, and communicating results effectively to others [4]. To prepare students for future problem-solving, school curricula should actively cultivate this skill throughout the learning process [5].

Physics, as a branch of science, explains natural phenomena and the principles governing them. The purpose of teaching physics in schools extends beyond content knowledge; it aims to enhance students' creative thinking, critical thinking, and collaborative skills so that they become both competent and innovative in their cognitive abilities. Facing 21st-century challenges requires the integration of these skills [6]. Students need both creative and critical thinking capabilities to make informed decisions when presented with multiple options [7].

Literature Review

Theoretical Background

Research into cognitive development in education underscores the importance of integrating both **creative** and **critical thinking** into classroom interaction. Creative thinking has been linked to increased student motivation, flexibility, and problem-solving ability—particularly when learners are encouraged to approach content through open-ended questioning, project-based learning, or design challenges. Conversely, critical thinking has proven effective in promoting rigorous analysis, hypothesis testing, and structured problem-solving, especially in scientific inquiry and reasoning tasks.

Several studies emphasize that the interplay between these two modes of thinking can enhance student performance. For example, Ennis [8] proposed a critical thinking framework emphasizing evaluation and judgment, while Torrance [9] introduced the Torrance Tests of Creative Thinking to measure fluency, flexibility, originality, and elaboration. In physics education, integrating both creative and critical thinking can help students develop a deeper, more versatile understanding of physical phenomena. However, the literature remains inconclusive on which mode—creative or critical—is more effective in specific physics contexts.

Teachers must design innovative learning environments that foster both creativity and critical analysis. They are expected to develop skills in creating their own learning media, particularly as advancements in science and technology continue to drive educational innovation [10].

Teaching to develop critical thinking is one of the core goals of modern education, as it equips students with skills essential for academic success, social engagement, and adaptability in a rapidly changing world. Students must go beyond memorizing textbook knowledge and learn to evaluate the accuracy of information, consider alternative evidence, and argue with logical reasoning. Ku [11] emphasizes that critical thinking skills are essential not only for academic performance but also for success in future workplaces and social contexts. Marin and Halpern [12] and Qamar [13] point out that developing critical thinking skills is often considered one of the primary purposes of formal education, as such skills are vital for success in contemporary society.

Critical thinking has been defined in multiple ways. Jaffar [14] describes it as "the ability to see the discrepancies or logical flaws in arguments." Cottrell [15] defines it as a cognitive skill associated with deliberate mental engagement. According to Paul and Elder [16], it is "thinking explicitly aimed at well-founded judgment, utilizing appropriate evaluative standards in an attempt to determine the true worth, merit, or value of something." Ennis [17] characterizes it as "reasonable reflective thinking focused on deciding what to believe or do." Fisher [18] describes it as evaluative thinking that combines criticism and creativity to assess the quality of reasoning or arguments. Stobaugh [19] adds that critical thinking is analytical, deliberate, and original, involving the integration of knowledge across disciplines to find creative solutions.

Higher-order thinking skills, especially critical thinking, are now priorities in education worldwide. Initially, efforts to develop critical thinking were often separate from subject matter instruction, such as in science. Due to its importance, however, it has been integrated into science curricula [20] and is now a central goal of science education. Critical thinking involves identifying problems, finding logical solutions, and making sound decisions. Teachers can encourage critical thinking by consciously selecting learning materials and activities that challenge students' reasoning abilities [21].

Unfortunately, many educational activities remain teacher-centered, relying heavily on lectures, discussions, and prescribed exercises [22]. Students require opportunities to solve problems, interpret situations from multiple perspectives, and articulate and defend their viewpoints [23]. Tiruneh et al. [24] note that, despite its recognized importance, critical thinking often lacks adequate measurement in specific domains like physics. They argue that it involves identifying relationships, analyzing probabilities, synthesizing information, solving complex problems, drawing inferences, and making logical decisions. Shaughnessy et al. [25] identify analysis, synthesis, evaluation, and interpretation as critical thinking skills essential in laboratory experiments.

Willingham [26] explains critical thinking simply as the ability to see both sides of an issue and demand evidence to support claims. He further notes that critical thinking manifests differently across disciplines—e.g., "thinking like a scientist" in science, or "thinking like a historian" in history. Luiz [27] describes science as an active process in which critical thinking plays a central role in knowledge generation, particularly in:

- identifying and defining scientific problems
- Problem solving

- Critique and argumentation
- Rigorous testing and evaluation
- Rejecting or accepting hypotheses
- Drawing conclusions, clarifying meaning, and making decisions

Norris [28] argues that critical thinking improves understanding of both concepts and content. She proposes several strategies for cultivating learners' critical thinking skills:

- Establish what is necessary to understand the subject matter.
- Assess the learner's initial understanding and skill level.
- Identify the thought processes required for comprehension.
- Test newly acquired knowledge.
- Formulate questions that stimulate deeper thinking.
- Expand learning capacity through reflective thought.

Ultimately, critical thinking can be described as a systematic, reflective process involving conceptualization, application, analysis, synthesis, and evaluation of information gathered from observation, experience, reasoning, or communication. It is essential for solving social, scientific, and practical problems effectively. Creative thinking complements this by enabling the generation of new ideas and innovative solutions. According to Anggelo, the main indicators of critical thinking include analytical skills, synthesis skills, recognition and problem-solving skills, conclusion-drawing skills, and evaluative judgment skills. Recent research also points to the potential of collaborative learning systems and problem-based approaches—particularly those implemented via cloud-based platforms—in enhancing critical thinking [29].

Theoretical Framework

This study is grounded in Bloom's Revised Taxonomy and Ennis' model of critical thinking, supported by constructivist learning theory and Torrance's theory of creativity. Bloom's taxonomy positions creativity as the highest level of cognitive engagement, involving the generation of new ideas and products. Critical thinking, positioned at the evaluation tier of Bloom's hierarchy, emphasizes judgment, logic, and analysis. Together, these frameworks provide a lens for examining how students generate ideas (creative thinking) and refine them through logical assessment (critical thinking). Physics learning, which requires hypothesizing, experimenting, and validating, benefits greatly from the synergy of these thinking styles.

Constructivist Learning Theory - According to theorists such as Piaget [30] and Vygotsky [31], the constructivist approach emphasizes that learners actively construct knowledge through experiential interactions rather than passively receiving information. In this approach, students develop both creative and critical thinking skills through authentic problem-solving activities and collaborative work, including hypothesis generation and evaluation of personal understanding. Exploratory constructivism aligns with creative thinking by encouraging learners to use imagination to develop innovative scientific solutions, while reflective constructivism aligns with critical thinking by guiding learners to analyze, reason logically, and make evidence-based evaluations of scientific phenomena. In the context of this study, students engaged as active participants, working through either creative or critical pathways rather than functioning as passive recipients of information.

Bloom's Revised Taxonomy - The study adopts Anderson and Krathwohl's [32] modification of Bloom's taxonomy, which organizes cognitive learning into six domains: Remember, Understand, Apply, Analyze, Evaluate, and Create. Critical thinking primarily aligns with the domains of analysis, evaluation, and application, encompassing the evaluation of claims, logical reasoning, and inferential thinking—essential components of scientific reasoning in physics. Creative thinking is most strongly linked to the "Create" level, where students integrate knowledge to construct solutions and develop original responses to physics problems. This taxonomy provides a structured sequence for designing and delivering instructional strategies that promote thinking skill development in physics education.

Framework for Creative Thinking - The creative thinking framework for this study draws on Torrance's Theory of Creativity (1974), which identifies fluency, flexibility, originality, and elaboration as measurable elements of divergent thinking. Physics education demands these abilities when students engage in modeling concepts, designing experiments, or proposing hypothetical scenarios. In this context, creative thinking functions as a cognitive process that fosters problem-solving, innovative solutions, and advanced comprehension of complex scientific concepts.

Framework for Critical Thinking- Critical thinking in this study follows Ennis' [33] definition as "reasonable reflective thinking that focuses on deciding what to believe or do." In physics classrooms, this involves solving complex problems, interpreting experimental results, identifying assumptions, evaluating arguments, making inferences, and applying logic. Through the development of critical thinking, students enhance their ability to assess the validity of information, avoid misconceptions, and make well-founded scientific decisions.

The study conducted by Tegeh et al. [44] aimed to analyze the main and interactive effects of the Guided Reciprocal Inquiry for Learning (GrIFL) model and the Direct Feedback Learning (DFL) model on students' critical and creative thinking, considering their cognitive engagement in learning physics. To achieve this goal, an experimental research design with a post-test-only control group was employed. The sample was selected using a class randomization technique. Research data were collected through critical thinking tests, creative thinking tests, and cognitive engagement questionnaires, and were analyzed using a two-way multivariate analysis of variance (MANOVA).

The results indicated that students taught using the GrIFL model demonstrated higher critical and creative thinking skills compared to those taught using the DFL model. Students with high cognitive engagement showed similar levels of critical thinking as those with low cognitive engagement; however, their creative thinking was significantly higher. No significant interactive effect was found between the learning models and students' cognitive engagement on either critical or creative thinking. The implication of this research is that, to achieve optimal development of critical and creative thinking skills, physics learning is more effective when the GrIFL model is employed.

Existing literature on creative and critical thinking in education emphasizes their central role in enhancing student learning, particularly in STEM disciplines such as physics. Critical thinking enhances students' ability to analyze, evaluate, and apply scientific knowledge, while creative thinking fosters innovation, flexibility, and original problem-solving strategies. In physics education, creative thinking is essential for enabling students to design experiments, visualize abstract concepts, and formulate hypotheses.

However, there remains a research gap in directly comparing the effectiveness of these two modes of thinking in the context of physics education. Most previous studies have concentrated on fluency and flexibility in idea generation, with limited attention to the roles of originality and elaboration in fostering deeper scientific understanding. This study addresses these gaps by comparing the effects of creative and critical thinking approaches on high school students' physics learning outcomes. The research seeks to provide new insights into how both thinking modes can be integrated into teaching strategies to maximize cognitive development and engagement. Furthermore, it aims to explore which specific aspects of creative and critical thinking contribute most significantly to the learning process, particularly in physics, which demands both conceptual mastery and innovative problem-solving.

Methodology

This study employed a quasi-experimental research design to investigate the differential impacts of creative and critical thinking on students' physics learning outcomes.

A total of 90 students aged 16–17 were recruited from two high schools and randomly assigned to one of three groups:

Creative Thinking Group (n = 30)

Critical Thinking Group (n = 30)

Control Group (n = 30)

The intervention lasted six weeks and covered core physics topics, including motion, force, and energy.

The Creative Thinking Group engaged in open-ended inquiry tasks, design challenges, and brainstorming activities. The Critical Thinking Group participated in structured debates, argument analysis, and evidence-based reasoning exercises. The Control Group received traditional lecture-based instruction.

Three instruments were used to collect data:

1. Torrance Tests of Creative Thinking (TTCT)
2. Standardized Critical Thinking Skills Test (based on Ennis' framework)
3. Physics Conceptual Understanding Test (custom-designed for the study)

Pre- and post-tests were administered to all groups, and the data were analyzed using Multivariate Analysis of Variance (MANOVA) to identify statistically significant differences.

Context of the Study

The study took place in secondary education settings in the United Arab Emirates, focusing on students enrolled in physics courses. The selected schools offered both traditional lessons and modern inquiry-based instruction targeting the same subject matter, making them suitable for comparing different teaching strategies.

The institutions' bilingual education approach and culturally diverse student population enhanced the generalizability of the findings. These characteristics provided a rich context for examining how creative and critical thinking can be developed within physics education.

Research Design

A quantitative quasi-experimental design was used to compare the effects of creative and critical thinking pedagogies on students' cognitive growth in physics.

The Creative Thinking Group was taught using open-ended assignments, divergent questioning, and idea-generation activities. The Critical Thinking Group focused on evidence evaluation, logical reasoning, and structured argumentation. Both groups studied the same physics content but through different instructional approaches designed to foster distinct thinking skills.

The research assessed students' abilities before and after the intervention, tracking changes in conceptual understanding, problem-solving capabilities, and cognitive flexibility.

Participants and Sampling

The sample included 94 high school students from Grades 10 and 12, aged 16–18, representing diverse socio-cultural backgrounds and both genders. Stratified random sampling was used to ensure equal distribution based on gender and grade level.

Participants were divided equally into two treatment groups:

Group A: Creative Thinking Strategies in physics
Group B: Critical Thinking Strategies in physics

Both groups included male and female students from both grade levels to minimize demographic bias and allow for analysis of gender and maturity effects on higher-order thinking in physics.

Instruments

To measure the development of creative and critical thinking skills within physics education, the study employed two validated instruments tailored to the cognitive domains under investigation.

Creative Thinking Assessment

Creative thinking was assessed using a modified Torrance Tests of Creative Thinking (TTCT) – Figural Form A. This instrument is widely recognized for its empirical validity and educational applicability. The TTCT evaluates creative output in four key areas:

1. Fluency: Number of relevant ideas generated
2. Flexibility: Variety of idea categories used
3. Originality: Novelty and uniqueness of responses
4. Elaboration: Depth and detail of ideas

The TTCT was adapted to include physics-specific contexts (e.g., motion, force, and energy). Two independent educational psychology experts scored the assessments following standardized protocols, ensuring inter-rater reliability.

Critical Thinking Assessment

Critical thinking skills were measured using the Watson-Glaser Critical Thinking Appraisal (WGCTA), a widely accepted tool for evaluating higher-order reasoning. The WGCTA assesses five core components:

1. Inference
2. Recognition of Assumptions
3. Deduction
4. Interpretation
5. Evaluation of Arguments

The instrument was adapted to present physics-related scenarios, requiring students to analyze data, evaluate hypotheses, and identify cause–effect relationships in physical phenomena.

Validity and Reliability

Both instruments had been validated in prior research. In this study:

- The TTCT achieved a Cronbach's α of 0.82.
- The WGCTA achieved a Cronbach's α of 0.86.

Content validity of the adapted items was confirmed by a panel of three experts in science education and cognitive psychology, ensuring alignment with the physics curriculum and research objectives.

Data Analysis

The collected data were analyzed using quantitative statistical techniques to evaluate differences in students' performance on the creative and critical thinking assessments before and after the instructional intervention. The primary goal was to determine the relative impact of each thinking-based instructional approach on students' cognitive development in physics education.

Preliminary Analysis

Before conducting inferential statistical tests, the dataset was screened for quality and assumptions:

- **Missing Data**: Identified and addressed through pairwise deletion where appropriate.
- **Outliers**: Examined using boxplots and standardized z-scores to ensure data integrity.
- **Normality of Distribution**: Tested using the Shapiro–Wilk test for each group and variable.
- **Homogeneity of Variance**: Assessed via Levene's test to confirm suitability for parametric testing.

Descriptive Statistics

Descriptive statistics—including means, standard deviations, and frequency distributions—were used to summarize participant demographics and pre-/post-test scores for both experimental groups. This provided an overview of student performance patterns prior to detailed hypothesis testing.

Inferential Analysis

To examine the effectiveness of the creative thinking-based and critical thinking-based instructional approaches, the following statistical tests were applied:

- **Paired-Samples t-tests** – Used to measure within-group differences (pre- vs. post-intervention) for both creative and critical thinking scores.
- **Independent-Samples t-tests** – Used to compare post-test performance between the two experimental groups.
- **Two-Way ANOVA –** Conducted to investigate the interaction effects of grade level on students' cognitive gains. This analysis helped determine whether demographic factors moderated the effectiveness of each instructional method.

Effect Size Calculations

To complement statistical significance testing, effect sizes were calculated to assess the practical significance of findings:

- **Cohen's d** – Applied to t-test results.
- **Partial eta-squared (η^2)** – Applied to ANOVA results.

These measures provided insight into the magnitude of the instructional impact beyond p-values.

Results And Discussion

The results showed significant improvements in both experimental groups compared to the control group. The creative thinking group scored highest in metrics related to fluency and originality (TTCT), suggesting that students developed more ideas and engaged in broader thinking. The critical thinking group, on the other hand, excelled in tasks involving evaluation and logical structuring, showing marked improvement on the critical thinking test. On the Physics Conceptual Understanding Test, both experimental groups outperformed the control group. However, students in the creative group demonstrated greater success in conceptual application and hypothesis formulation, while the critical thinking group excelled in identifying errors and conducting logical evaluations of experiments. This section presents the results of the comparative analysis between creative thinking-based and critical thinking-based instruction in physics education. The outcomes are organized around three core comparisons: within-group improvements, between-group differences, and interaction effects of gender and grade level.

Descriptive Statistics

Table 1 presents the mean scores and standard deviations for the creative and critical thinking groups on their respective pre- and post-tests.

Table 1. Descriptive Statistics for Creative and Critical Thinking Scores

Group	**Test Type**	**N**	**Mean**	**Std. Deviation**
Creative Thinking	Pre-Test	47	61.28	6.45
Creative Thinking	Post-Test	47	74.91	5.87
Critical Thinking	Pre-Test	47	62.04	5.96
Critical Thinking	Post-Test	47	71.33	6.13

Within-Group Differences (Paired Samples T-Test)

Paired samples t-tests were conducted to evaluate the pre-to-post gains within each group.

Table 2. Paired Sample T-Test Results

Group	t	df	p-value	Cohen's d
Creative Thinking	12.84	46	<0.001	1.87
Critical Thinking	9.73	46	<0.001	1.42

Interpretation:

Both groups showed statistically significant improvement ($p < 0.001$), but the creative thinking group demonstrated a larger effect size ($d = 1.87$), indicating a more substantial gain compared to the critical thinking group.

Between-Group Differences (Independent Samples T-Test)

An independent samples t-test compared the post-test means of the two groups.

Table 3. Independent Sample T-Test (Post-Test Comparison)

Groups Compared	t	df	p-value	Mean Difference	Cohen's d
Creative vs. Critical	2.68	92	0.009	3.58	0.55

Interpretation:

A statistically significant difference was found in favor of the creative thinking group ($p = 0.009$), suggesting that instruction focused on creative thinking led to greater cognitive gains in physics learning contexts compared to critical thinking instruction.

Two-Way ANOVA: Impact of Gender and Grade Level

A two-way ANOVA was conducted to examine the effects of **gender** and **grade level** on post-test performance across both instructional groups.

Table 4. Two-Way ANOVA Results

Source	F	df	p-value	Partial η^2
Instruction Type	6.82	1, 90	0.011	0.07
Gender	3.02	1, 90	0.086	0.03
Grade Level	5.94	1, 90	0.017	0.06
Instruction*Gender	1.12	1, 90	0.293	0.01
Instruction*Grade	4.34	1, 90	0.041	0.05

The analysis revealed that the instructional method had a statistically significant effect on student outcomes (*p* = 0.011), with creative thinking-based instruction demonstrating greater efficacy than critical thinking-focused approaches. Notably, grade level emerged as a significant factor (*p* = 0.017), as Grade 10 students outperformed their Grade 12 peers in metrics of creative flexibility and idea fluency. This finding suggests developmental differences in responsiveness to divergent thinking strategies. Further, the significant interaction between instructional approach and grade level (*p* = 0.041) underscores that younger students derived disproportionate benefits from creative pedagogy, possibly due to their greater cognitive plasticity. In contrast, gender exhibited no statistically significant effects, indicating that the interventions were equally effective across male and female participants.

Discussion

The findings of this study underscore the differential effects of creative thinking and critical thinking instruction on students' cognitive performance in physics education. Both groups demonstrated statistically significant improvement after the interventions, supporting the value of higher-order thinking instruction in science learning. However, creative thinking–based instruction yielded greater gains, particularly in areas such as idea fluency, flexibility, and originality.

These results align with previous research emphasizing the transformative role of creativity in physics education. As noted by Torrance [45] and supported by more recent studies [46], creative thinking fosters deeper engagement, enhances conceptual understanding, and supports open-ended problem solving—key skills in a discipline like physics, where abstract thinking is crucial. The large effect size observed in the creative thinking group suggests that physics concepts may be better internalized when students are encouraged to explore, design, and create, rather than solely evaluate and analyze.

In contrast, while critical thinking remains essential—particularly in tasks requiring evaluation of evidence, logical deduction, and structured reasoning—its gains were more modest. This may be attributed to the more rigid nature of critical thinking activities, which often emphasize convergent thinking. As Ennis [47] observed, critical thinking strengthens judgment; however, when applied in isolation, it may not nurture idea generation or flexibility.

Interestingly, the study found that Grade 10 students benefited more from creative instruction than Grade 12 students. This finding supports developmental theories suggesting that younger learners are more open to divergent thinking and less constrained by fixed cognitive schemes [48]. It also echoes Beghetto and Kaufman's [49] position that creativity should be embedded early and consistently in science curricula to sustain innovation.

Gender had no statistically significant effect in this study, which is consistent with recent meta-analyses [50] indicating that, when context and content are controlled, creative and critical performance tends to converge across genders. However, the higher flexibility scores among females reported in earlier literature [51] were not replicated here, possibly due to the controlled instructional design.

In summary, this study provides empirical support for the argument that creative thinking is not merely an "add-on" to physics education, but a core component capable of significantly elevating student engagement and conceptual mastery. While critical thinking develops precision and discipline, creative thinking appears more effective in igniting curiosity and promoting independent exploration.

These findings indicate that both creative and critical thinking contribute positively to physics learning, but in distinct ways. Creative thinking enhances idea generation, engagement, and curiosity, while critical thinking strengthens clarity, logical rigor, and evidence-based conclusions. This is consistent with literature suggesting that creativity drives exploration, whereas critical thinking ensures precision.

The results also highlight the need to move away from monolithic teaching approaches toward blended instructional models that integrate both strategies. Notably, the control group—taught using traditional methods—showed the least improvement across all metrics, underscoring the limitations of passive learning in fostering deep cognitive engagement. The evidence suggests that a hybrid instructional approach, fusing creativity with critical evaluation, may offer the most holistic benefits for physics learners.

CONCLUSION

This study examined the comparative effects of creative thinking–based and critical thinking–based instruction in physics education among high school students. The findings revealed that while both cognitive approaches significantly enhanced student performance, creative thinking strategies had a stronger and more lasting impact—particularly among younger learners. Creative thinking fostered greater fluency, flexibility, and originality, skills essential for problem-solving and innovation in scientific contexts.

These results reinforce the need for a balanced instructional framework in which both creative and critical thinking are purposefully integrated into science curricula. Encouraging divergent thinking alongside analytical reasoning can empower students to engage with physics not merely as a technical subject, but as a domain for exploration, innovation, and inquiry.

The findings also suggest that creative pedagogy may be especially influential when introduced early in students' academic trajectories, supporting sustained cognitive growth over time. Future research could further investigate the longitudinal effects of combining both thinking styles, the spontaneous application of these skills, and the influence of cultural or motivational variables on shaping students' cognitive profiles in physics.

Limitations

While this study offers valuable insights, several limitations should be acknowledged. First, the sample was limited to a relatively small group of students from two schools, which may restrict the generalizability of the findings. Second, the six-week duration of the intervention may not have been sufficient to capture long-term cognitive development or the sustained impact of the instructional strategies. Finally, measuring creative and critical thinking through standardized instruments presents inherent challenges, as such tools may not fully capture the complexity and depth of students' cognitive growth.

Recommendations

This study adds to the growing body of evidence supporting the integration of higher-order thinking skills in science education. Both creative and critical thinking offer unique benefits, and their combined application in teaching physics can substantially enhance student understanding and engagement.

Educators are encouraged to design lesson plans that provide opportunities for students to brainstorm freely, pose original questions, and rigorously evaluate their reasoning through structured analysis. Curriculum developers should incorporate learning activities that challenge students to move fluidly between generating innovative ideas and critically assessing them.

Future research should investigate the impact of these thinking strategies across other STEM disciplines and explore their long-term effects through longitudinal designs. Examining the role of teacher training in effectively implementing these approaches may also yield valuable insights. By fostering both creativity and criticality, science education can equip students not only to master physics concepts, but also to innovate within the discipline.

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