iEducation, 2026, 2(2), 29-53
https://doi.org/10.71204/xbferv14

Can Science Games (SGs) Foster Creative Thinking? Evidence from a Mixed-Methods Study of Primary School Students

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Received: 3 June 2026 /Accepted: 29 June 2026 / Published online: 30 June 2026

Abstract

Creative thinking is a critical dimension of scientific thinking, as stipulated in the Science Curriculum Standards for Compulsory Education (2022 Edition), and is a key component in cultivating primary school students' core scientific literacy. The Science Games (SGs), an important practical vehicle in primary and secondary science education that draws on the sports competition model while creating high-tech, authentic problem-solving contexts, have been widely adopted in campus-based science education activities. Current scholarly inquiries have predominantly focused on the effects of subject teaching, programming projects, and inquiry-based learning on students' creative thinking, whereas empirical investigations specifically addressing the development of primary school students' creative thinking within the SGs setting remain considerably scarce, and the educational outcomes and characteristic effects of such activities lack systematic examination. This study recruited 13 primary school students from the 6th Zhengzhou Primary and Secondary School SGs as research participants. Employing a multimethod approach—including pre- and post-intervention measurements using the Williams Creativity Assessment Packet, semi-structured interviews, and teacher observation records—the study conducted a longitudinal comparative analysis of students' creative thinking development across the activity cycle of the SGs. The findings reveal that participation in the SGs significantly influences all dimensions of primary school students' creative thinking, effectively enhancing their performance in terms of challenge, imagination, curiosity, and risk-taking. Furthermore, the activity compensates for the deficiencies of traditional science instruction, such as insufficient practical inquiry and overly uniform models of innovation training. This study elucidates the unique educational value of the SGs in fostering scientific thinking and innovative capacity among primary school students, thereby providing both empirical evidence and theoretical reference for the practical cultivation of creative thinking in primary science education and the educational promotion of science and technology competition activities.

Keywords: Science Games; Creative Thinking; Primary School Students

1. Introduction

Strengthening science education at the basic education stage is a key initiative for enhancing scientific literacy and enriching the reserve of scientific and technological innovation talents. In the new era, the state has attached great importance to improving the quality and efficiency of science education in primary and secondary schools. It has successively issued several top-level policy documents that chart the direction for science education development. The Ministry of Education issued the *Opinions of the Ministry of Education and Eighteen Other Departments on Strengthening Science Education in Primary and Secondary Schools in the New Era* (Ministry of Education et al., 2023) and *the Guidelines for Science Education in Primary and Secondary Schools*(Ministry of Education, 2025), among other documents, which explicitly call for the implementation of science education in primary and secondary schools with a focus on core competencies such as scientific concepts, scientific thinking, inquiry-based practice, and attitudinal responsibility. These documents advocate advancing science education grounded in inquiry-based practice, stimulating primary and secondary school students' curiosity, imagination, and desire to explore, and cultivating students' interest in science.

Among the core competencies that science education aims to cultivate, scientific thinking occupies a pivotal position. *The Science Curriculum Standards for Compulsory Education (2022 Edition)* (Ministry of Education, 2022) points out that scientific thinking — including model construction, reasoning and argumentation, and creative thinking — is the core of the scientific literacy that science curricula aim to cultivate. As a core component of scientific thinking, creative thinking is a key competence for students to identify problems, propose solutions, and generate novel insights. It constitutes an essential competency that science education in the new era strives to develop. Therefore, the cultivation of creative thinking in primary school educational practice serves as a practical bridge connecting the learning of scientific knowledge and the development of higher-order cognitive abilities. It represents a core pathway for stimulating students' curiosity, imagination, and exploratory drive, and its quality of cultivation directly affects the overall level of innovation capability development in primary science education. The cultivation of scientific and creative thinking is the ultimate goal of primary science instruction. Under the guidance of proper thinking, students are enabled to think independently, to question boldly, and to gain knowledge and accumulate experience through practice (wang, 2026).

To implement the requirements of the new curriculum standards, various regions have been actively exploring pathways for cultivating creative thinking. Science and technology competitions and practical activities, as effective pathways for cultivating innovative talents, have attracted increasing scholarly attention (Zhou, 2021; Yang et al., 2024). However, although creative thinking has been recognized as a core competency of 21st-century education, systematic research specifically targeting the cultivation of creative thinking in primary school students remains relatively scarce. Most existing studies have focused on subject-specific instruction, with insufficient exploration of the developmental patterns of creative thinking in informal learning contexts such as science and technology competitions and project-based activities. In particular, within the domain of science and technology competitions, prior research has largely concentrated on their facilitating effects on non-cognitive factors such as learning interest and hands-on practical skills, whereas limited attention has been paid to systematically examining the differentiated effects of such activities across various dimensions of creative thinking.

Against this backdrop, the Science Games (SGs), a comprehensive science and technology competition activity that integrates scientific inquiry, engineering design, hands-on practice, and teamwork, has been gradually promoted in the field of basic education in recent years (Luo, 2017; Zheng et al., 2025). This activity draws on the organizational model of sports competitions and places students in authentic and challenging problem-solving contexts. Its characteristics of "learning by doing" and "practicing through competition" are highly compatible with the intrinsic conditions for generating creative thinking. However, there remains a lack of longitudinal empirical studies based on a complete training-and-competition cycle that systematically examine the effects and mechanisms of the Science Games on primary school students' creative thinking. On this basis, this study focuses on students who participated in the 6th Zhengzhou Primary and Secondary School Science Games as research subjects. Employing a mixed-methods approach that combines pre- and post-intervention questionnaires, semi-structured interviews, and teacher observation records, this study investigates the influence of the Science Games on primary school students' creative thinking, aiming to provide empirical evidence and theoretical reference for expanding the pathways for cultivating creative thinking.

2. Literature Review

2.1. Conceptual Definition and Theoretical Development of Creative Thinking

Creative thinking is a core component of creativity, referring to an individual's ability to generate novel and valuable ideas or products. Guilford (1950), in his seminal study, proposed a multifactorial hypothesis of creativity, encompassing sensitivity to problems, ideational fluency, flexibility, novelty, and synthetic and analytical abilities. Subsequently, Guilford (1956) structure-of-intellect model provided a systematic framework for creativity research. Building on Guilford's work, Torrance (1974) developed the Torrance Tests of Creative Thinking (TTCT), further elaborating divergent thinking into measurable dimensions such as fluency, flexibility, originality, and elaboration. Building on the above research tradition centered on divergent thinking, contemporary researchers have further attended to the comprehensiveness of creative output. Wang et al. (2024) noted that novelty and appropriateness are two fundamental components of creativity, yet the neural and behavioral mechanisms underlying their dissociation remain unclear. To investigate this question, they combined behavioral experiments with functional magnetic resonance imaging. The findings suggest that semantic associative ability primarily predicted novelty, whereas executive control function primarily predicted appropriateness; at the neural level, novelty was associated with the default mode network, while appropriateness was associated with the limbic network. The above studies have deepened the understanding of creative thinking from cognitive processes and neural mechanisms, but creativity involves not only cognitive abilities but is also deeply influenced by individuals' affective attitudes and personality dispositions.

Distinct from the cognitive orientation discussed above, Williams (1993) attended to the affective dimension of creative personality and developed the Creativity Assessment Packet (CAP), which encompasses four dimensions: curiosity, imagination, risk-taking, and challenge. This instrument posits that creative thinking depends not only on cognitive abilities but is also profoundly shaped by individuals' affective attitudes and personality dispositions. Craft (2003) further extended creativity research to the primary education context, pointing out that the primary school years constitute a critical period for creativity development, during which teachers should stimulate students' curiosity and imaginative potential through appropriate instructional activities. Collectively, these theoretical contributions provide a robust framework for understanding the structure of primary school students' creative thinking and the pathways for its cultivation in the present study.

2.2. Measurement and Assessment of Creative Thinking in Primary School Students

Accurate and valid measurement instruments are fundamental to empirical research on creative thinking. Currently, the most widely applied instruments in international research include the TTCT developed by Torrance (1974) and the CAP developed by Williams (1993). However, Cooper (1991) conducted a critical review of six creativity measures, including the TTCT and CAP, and argued that these instruments can only serve as "partial" measures of divergent thinking, with limitations in internal validity, external validity, and construct definition. Kim (2006) systematically reviewed the reliability and validity of the TTCT, and the results indicate that it effectively predicts individuals' future creative achievements, making it one of the creativity tests with the strongest predictive validity to date. Kaufman et al. (2013) systematically reviewed methods for assessing creativity in children, emphasizing that multiple instruments—including divergent thinking tests, consensus assessment techniques, and affective questionnaires—should be combined to comprehensively capture children's creative potential.

In primary science education research, given that primary school students' cognitive development and language proficiency are not yet fully mature, the use of self-report affective questionnaires—such as the Williams Scale—offers favorable feasibility and acceptability. The Creativity Assessment Packet (CAP) was adapted into a Chinese version by Lin and Wang (1994), encompassing four dimensions—risk-taking, challenge, curiosity, and imagination—with a total of 50 items rated on a three-point scale. This instrument has been employed in multiple domestic studies to assess primary school students' creative tendency. The present study adopts this scale as the measurement tool, which aligns with the cognitive characteristics of upper-grade primary school students and can effectively capture changes in students' creative thinking across various dimensions before and after the SGs intervention.

2.3. Influencing Factors and Cultivation Pathways of Creative Thinking in Primary School Students

The development of primary school students' creative thinking is influenced by multiple factors, including individual, family, and school-level variables. Alves-Oliveira et al. (2022) conducted a systematic review of creativity intervention studies at the primary school level from 1950 to 2020, concluding that creativity is cultivable and that intervention effects vary according to methods and contexts. Said-Metwaly et al. (2021) performed a meta-analysis of divergent thinking development from first grade through high school senior year, and the results indicate that divergent thinking exhibited an overall upward trajectory, with no evidence of a pervasive "fourth-grade slump" phenomenon, indicating that primary school students are fully capable of rising to the developmental potential for innovative challenges. At the school-education level, Willemsen et al. (2024) implemented an inquiry-based learning intervention in upper-grade primary science education, and their data reveal that children's domain-general convergent thinking significantly improved, suggesting that inquiry-based practice holds potential value for fostering creative thinking.

In domestic research, He and Song (2026) further examined the issue from the perspective of teacher support, empirically finding that teachers' emotional support, cognitive support, and autonomy support all significantly and positively predicted primary school students' mathematical creative thinking, with cognitive support exerting the most prominent effect, suggesting that teachers' guidance and encouragement in daily instruction are key variables in stimulating students' creative thinking. Dong and Xu (2022) focused on programming education, constructing a teaching model for Scratch courses oriented toward five key characteristics of creative thinking—including initiative and originality—thereby providing a viable instructional pathway for cultivating primary school students' creative thinking through programming practice. Xu (2022), within the context of artificial intelligence education, adopted a project-based design themed "Smart Living" as an example, effectively cultivating primary school students' creative thinking by creating authentic problem situations and guiding students through the complete creative process of "needs analysis—prototype design—iterative optimization," further expanding the practical pathways for technology-empowered creative thinking cultivation. Synthesizing the above literature, the cultivation of creative thinking has progressed from theoretical discussion to empirical validation; however, existing intervention studies have predominantly focused on specific disciplinary contexts such as programming and science, with a lack of systematic investigation into teachers' instructional behaviors in daily classroom settings—this constitutes the entry point of the present study.

2.4. The Educational Value and Current Research Status of the SGs

The SGs, as a novel form of science education activity that integrates scientific knowledge, inquiry abilities, and competitive mechanisms, have gradually emerged in China's basic education sector in recent years. Such activities are typically organized by science and technology museums or education authorities, operating on an annual or semester-based cycle, and feature multiple events, including the "Ball Adventure Race," "Future Energy Challenge," and "Reaction Power Elite Competition." Its core characteristics lie in emphasizing the integration of science and technology, requiring students to complete design and fabrication tasks within limited time and resources, while also valuing comprehensive performance in teamwork and problem-solving abilities.

Theoretical discussions and empirical investigations concerning the educational functions of science and technology competitions have yielded preliminary findings in the existing literature.

Current studies indicate that participation in science and technology competitions exerts positive effects on enhancing students' scientific interest, hands-on operational skills, and problem-solving abilities. For instance, Zhang et al. (2025) confirmed that science and technology activities can significantly strengthen students' innovation awareness. Luo (2017) systematically articulated the concept of the "Science and Technology Games," pointing out that its essence lies in drawing upon the organizational model of sports competitions to construct competitive activities that integrate high technological content, strong inquiry orientation, and authentic contexts. This platform not only serves as a performance assessment vehicle for adolescents' scientific and technological innovation literacy and practical abilities, but also helps promote the normalization of comprehensive science and technology practical learning, while giving rise to new forms of public science and technology cultural and recreational activities. Furthermore, as reported by He (2017), media coverage has emphasized that the holding of Science and Technology Games fosters a science-learning atmosphere in which "everyone wants to play, everyone can play, and everyone loves to play," enabling students not only to enhance their learning motivation and cognitive competence through "learning by playing," but also to acquire important psychological literacy through coping with competition, engaging in teamwork, and adjusting to successes and failures. At the empirical level, several master's students from Guangxi Normal University have also conducted systematic investigations on the educational effectiveness of Science and Technology Games, further corroborating their unique value in cultivating non-cognitive abilities.

Meanwhile, some scholars have focused on the mechanisms underlying students' participation in science and technology competitions. Bai et al. (2024), based on a qualitative analysis grounded in grounded theory, identified three strategies for enhancing secondary school students' willingness to participate in science and technology competitions, aiming to facilitate behavioral transformation by strengthening participation motivation. The above studies have revealed the educational potential of science and technology competition activities from different perspectives and have provided useful conceptual frameworks for subsequent research.

However, a comprehensive review of the literature distribution and research foci of studies related to the SGs reveals that research output in this field remains relatively limited. Although existing studies have clearly identified the educational functions of such competitions and laid an initial foundation for subsequent exploration, systematic investigations that integrate the SGs with creative thinking development remain scarce, with empirical evidence specifically targeting primary school students in basic education being particularly weak. On this basis, the present study focuses on the specific context of the SGs, systematically examining its intrinsic relationship with the development of primary school students' creative thinking, intending to address the aforementioned limitations and provide both theoretical foundations and empirical support for a deeper understanding of the educational value of the SGs.

2.5. Theoretical Analysis

This section adopts the Componential Theory of Creativity proposed by Amabile (1983) as its analytical framework. This section identifies which core features of the Science Games may influence creative thinking through which pathways, thereby providing an analytical starting point for subsequent empirical research, while also drawing on existing empirical studies as supporting evidence.

Amabile's Componential Theory of Creativity posits that the realization of individual creativity depends on the interaction of three components: domain-relevant skills, creativity-relevant skills, and task motivation. One of the core propositions of this model is the distinction between intrinsic and extrinsic motivation: when individuals engage in activities out of interest, curiosity, or a sense of challenge, their thinking becomes more flexible and original; whereas extrinsic constraints—such as rewards, evaluation, and deadlines—may undermine intrinsic motivation and thus negatively affect creativity. Creativity-relevant skills encompass cognitive activities including divergent thinking, breaking mental sets, and examining problems from multiple perspectives, and can be activated by appropriate environmental cues.

According to this model, the activation of creativity-relevant skills requires environmental conditions characterized by openness, autonomy, and moderate challenge, while the stimulation of intrinsic motivation depends on interest, autonomous choice, and quality of feedback. The competitive context of the SGs provides precisely these conditions. Authentic problem situations with uncertain outcomes, such as the load-bearing design of the "Cross-Strait Bridge," evoke cognitive conflict and exploratory desire (Johnson and Howe, 1978). This points to the stimulation of intrinsic motivation. The openness of the design process requires students to repeatedly generate new ideas and explore multiple possibilities across diverse pathways, thereby engaging divergent thinking (Guilford, 1956). Each test result within the trial-and-error iteration cycle constitutes concrete informational feedback, which helps students gain a sense of competence through a positive cycle of "failure-analysis-progress" (Amabile and Pratt, 2016), thereby enhancing their resilience in the face of difficulties.

The above theoretical derivation can be preliminarily corroborated by existing empirical studies. Research on science and technology competitions has found that hands-on practice, mentor guidance, and challenging tasks within competitions are key factors driving students' STEM career choices and sustained development (Villalobos-González et al., 2026); Domestic research has also indicated that science and technology competitions play a positive role in stimulating innovation enthusiasm, cultivating teamwork, and enhancing practical skills (Yang et al., 2024). Taken together, the existing empirical evidence is consistent with the direction of the above theoretical derivation.

3. Methods

3.1. Research Questions and Objectives

This study addresses two primary research questions:

(1) What effect do the SGs have on students' creative thinking?

(2) How do the SGs influence students' creative thinking?

This study aims to examine the relationship between the SGs and the development of primary school students' creative thinking, to enrich the theoretical research on creative thinking cultivation among primary school students, to provide theoretical support for relevant educational practices, and to offer a novel pathway for schools and teachers to foster students' creative thinking.

3.2. Research Methods

This study adopted a mixed-methods research design to ensure the rigor and credibility of the findings. The research was conducted in a public primary school in Zhengzhou. Although the school is located at the junction of urban and rural areas, it places great emphasis on science curricula and science-related activities, and frequently organizes various science and technology events. Students at this school had prior experience participating in the Primary and Secondary School SGs and other science and technology competitions hosted by the Zhengzhou Science and Technology Museum, and they exhibited strong interest in related competition events. The study targeted students who participated in the 6th Primary and Secondary School SGs organized by the Zhengzhou Science and Technology Museum, which featured six events: the "Ball Adventure Race," "Future Energy Challenge," "Reaction Power Elite Competition," "High-Altitude Extreme Challenge," "Table Tennis Tower," and "Cross-Strait Bridge." These students were selected through multiple rounds of school-wide screening, ensuring a certain degree of representativeness. In the initial screening phase, 38 students were selected from the entire school based on their participation intentions, age characteristics, and other criteria as suitable candidates for the SGs. Subsequently, 26 students were selected for training based on their practical skills, scientific knowledge reserves, teamwork spirit, and psychological resilience. These 26 students were then divided into 12 groups according to their competition preferences, with two groups assigned to each event. During the subsequent training period, the training performance and scores of the two groups in each event determined which group would be selected to represent the school in the official competition. Ultimately, 13 students from this primary school who participated in the SGs constituted the research subjects of this study.

3.2.1. Survey Research

(1) Survey Participants

A total of 13 students from Primary School X who participated in the 6th Zhengzhou SGs were selected as the research subjects. Questionnaires were administered at two time points: before the commencement of the SGs training and immediately after the official competition. The questionnaires were distributed to the participating students at each respective time point, and the collected data were systematically organized and statistically analyzed. Before the SGs training, 26 pre-test questionnaires were distributed to the 26 students who had entered the preparatory training phase; all 26 were returned, yielding 26 valid responses. After the official competition concluded, 13 post-test questionnaires were distributed to the 13 students who ultimately participated in the competition; all 13 were returned, yielding 13 valid responses. In the data analysis phase, paired-sample tests were conducted by matching the pre-test data of the 13 final participants with their post-test data.

(2) Survey Instrument

This study employed the Creativity Assessment Packet (CAP) as revised by Lin and Wang. This instrument is widely used in psychology and education to assess individuals' creative tendencies. Originally designed by American psychologist Frank E. Williams and subsequently adapted by Taiwanese scholars Lin and Wang, the scale encompasses four dimensions—curiosity, imagination, risk-taking, and challenge—with a total of 50 items rated on a three-point scale. It is used to measure individual performance on creativity-related personality traits.

3.2.2. Interview Method

(1) Interview Participant Selection

After the competition concluded, interviews were conducted with the participating students and their teachers regarding changes in students' classroom performance and creative thinking. A total of 3 teachers of the participating students from Primary School X and 3 participating students from Primary School X were interviewed. The interviews focused primarily on "students' classroom performance" and "changes in students' creative thinking."

(2) Interview Protocol

For Teachers:

What differences, if any, have you observed in students' classroom performance before and after they participated in the SGs?

What changes, if any, have you observed in the creative thinking of students who participated in the SGs?

These two questions were designed to capture, from the classroom teachers' perspective, changes in students' classroom performance and creative thinking following their participation in the SGs. This approach not only allowed us to collect evidence regarding the impact of the SGs on students' creative thinking, but also enabled us to understand how these changes subsequently influenced their classroom performance.

For Students:

What changes have you noticed in your classroom performance before and after participating in the SGs?

What changes, if any, have you experienced in terms of risk-taking, challenge, imagination, and curiosity before and after your participation in the SGs?

The question, "What changes, if any, have you experienced in your classroom performance before and after you participated in the SGs?" was designed to understand the impact of the SGs on students' classroom performance and to explore whether the SGs can stimulate students' interest in science learning. The question, "What changes, if any, have you experienced in terms of risk-taking, challenge, imagination, and curiosity before and after your participation in the SGs?" was designed to capture the impact of the SGs on students' creative thinking from the perspective of its four dimensions.

3.2.3. Observational Records

Throughout the entire process from training to competition, the researcher (who also served as an instructor for some of the events) participated in the instructional setting in the capacity of a daily facilitator, documenting students' behavioral performance at various stages through sustained observational notes. The observation was conducted in three phases: in the initial phase, the focus was on students' baseline levels of initiative, willingness to express themselves, and cooperative awareness; in the middle phase, attention was directed toward behavioral changes during intervention activities such as brainstorming and trial-and-error methods; in the final phase, the emphasis shifted to students' adaptive responsiveness and problem-solving performance during competition preparation and actual contest scenarios. The observational findings from each phase were recorded in the form of instructional logs, serving as process-based evidence for subsequent analysis of the developmental trajectory of students' creative thinking.

3.3. Implementation Process of Science Games

The current edition of the SGs featured a total of six competition events (Ball Adventure Race, Future Energy Challenge, Reaction Power Elite Competition, High-Altitude Extreme Challenge, Table Tennis Tower, and Cross-Strait Bridge). Each event required students to complete the design and fabrication of their works on site within a limited time, with rankings determined by competitive performance. The training cycle spanned four weeks: Week 1 served as basic skills training, during which students familiarized themselves with event rules and tool usage and acquired fundamental fabrication methods. Weeks 2 to 3 were dedicated to scheme design and iterative optimization, in which students worked in groups to conceptualize and fabricate their designs, continuously improving them through repeated testing. Week 4 consisted of a mock competition to verify the stability of their works and adapt to the competition rhythm.

4. Results

4.1. Comparative Analysis of Pre-test and Post-test Measures of Creative Thinking

4.1.1. Comparative Analysis of Pre-test and Post-test Total Scale Scores

Before conducting the pre-post difference comparison, this study first performed a normality test on the difference scores. Due to the small sample size ($n = 13$), the Shapiro-Wilk test was employed as the primary criterion. The results indicated that the difference scores conformed to a normal distribution ($W = 0.956$, $p = 0.698$), which did not statistically reject the assumptions underlying parametric tests. However, under small-sample conditions ($n < 20$), the statistical power advantage of parametric tests is extremely limited. Moreover, normality tests themselves have insufficient capacity to detect subtle deviations in distributional tails, and parametric tests are sensitive to outliers and changes in distributional shape. To enhance the robustness of the statistical conclusions, this study selected the paired-sample Wilcoxon signed-rank test, which imposes no special requirements on data distribution, as the primary statistical inference method.

The Williams Creativity Assessment Packet has a maximum total score of 150 points. Following data collection, the pre-test and post-test total scores were systematically compiled and analyzed. Paired-sample Wilcoxon signed-rank tests were subsequently conducted on the pre-test and post-test data using SPSS software. The analytical results of the paired-sample Wilcoxon signed-rank test for the total scores of the Williams Creativity Assessment Packet are presented in Table 1.

Table 1. Paired-Sample Wilcoxon Signed-Rank Test Results for Total Scale Scores Between Pre-Test and Post-Test

Group	Mean	Median（p25，p75）	Wilcoxon Signed- Rank Test	
			Z	p
Pre-test Total Score	111.5	114（107，117）	-3.182	0.001
Post-test Total Score	127.9	129（124，133）		

As shown in Table 1, the mean total score on the Williams Creativity Assessment increased from 111.5 before the SGs' participation to 127.9 following participation, representing an improvement of 14.7%. The median total score rose from 114 in the pre-test to 129 in the post-test, reflecting an increase of 15 points. The significance level ($p < 0.01$) indicated a statistically significant difference, indicating that students showed significant improvements after participating in the SGs.

4.1.2. Comparison of Subscale Scores Between Pre-Test and Post-Test Across Dimensions

The subscale scores for the four dimensions were as follows: risk-taking (total possible score = 33), challenge (total possible score = 36), imagination (total possible score = 39), and curiosity (total possible score = 42). Descriptive statistics were calculated for each of the four dimensions, followed by paired-sample Wilcoxon signed-rank tests on the dimensional scores. The results are presented below.

(1) Pre – Post Dimensional Score Comparisons on the Williams Creativity Assessment are presented in Table 2.

Table 2. Wilcoxon Signed-Rank Test Results for Subscale Scores by Dimension

Dimension	Median（p25，p75）		Wilcoxon Signed-Rank Test	
	Pre-test	Post-test	Z	p
Risk-taking	25（24，27）	29（26.5，30）	-2.288	0.022
Challenge	27（25，29）	31（30，33）	-2.766	0.006
Imagination	28（23.5，30.5）	32（29，33.5）	-2.561	0.01
Curiosity	32（30，34.5）	39（35，39.5）	-2.275	0.023

As shown in Table 2, the median score for the risk-taking dimension increased from 25 before participation in the SGs to 29 after participation, reflecting an improvement of 4 points. The significance level ($p < 0.05$) indicated a statistically significant difference, suggesting that students' risk-taking significantly improved following the SGs.

For the challenge dimension, the median score increased from 27 before participation to 31 after participation, also showing an improvement of 4 points. The significance level ($p < 0.01$) indicated a statistically significant difference, suggesting that students' challenge orientation significantly improved following the SGs.

For the imagination dimension, the median score increased from 28 before participation to 32 after participation, representing an improvement of 4 points. The significance level ($p < 0.05$) indicated a statistically significant difference, suggesting that students' imagination significantly improved following the SGs.

For the curiosity dimension, the median score increased from 32 before participation to 39 after participation, reflecting an improvement of 7 points. The significance level ($p < 0.05$) indicated a statistically significant difference, suggesting that students' curiosity significantly improved following the SGs.

(2) The mean scores of each dimension of the Williams Creativity Assessment Packet in the pre-test and post-test are presented in Table 3.

Table 3. Comparison of Pre-Test and Post-Test Mean Scores Across Subscales

Group	Risk-taking	Challenge	Imagination	Curiosity
Pre-test	25.7	26.7	27.0	32.1
Post-test	28.5	31.9	31.4	36.4

As shown in Table 3, before participating in the SGs, students' mean score for risk-taking was 25.7; following participation, it rose to 28.5, representing an increase of 10.9%. For the challenge, the mean score increased from 26.7 before participation to 31.9 after participation, a 19.5% increase. For imagination, the mean score increased from 27.0 before participation to 31.4 after participation, a 16.3% increase. Out of curiosity, the mean score increased from 32.1 before participation to 36.4 after participation, a 13.4% increase. These results indicate that after participating in the SGs, students' mean scores across all four dimensions—risk-taking, challenge, imagination, and curiosity—improved.

4.2. Analysis of Teacher and Student Interview Results

After the competition concluded, semi-structured interviews were conducted with both the participating students and their classroom teachers to further understand the impact of the SGs on students. The interviewees included three classroom teachers of the participating students from Primary School X (coded as T1, T2, and T3) and three participating students from Primary School X (coded as S1, S2, and S3). The interviews focused primarily on changes in students' "classroom performance" and "creative thinking," with detailed analyses presented below.

4.2.1. Analysis of Teacher Interview Results

(1) Changes in Classroom Performance

When asked about the differences in students' classroom performance following their participation in the SGs, most teachers observed positive and notable changes. Teacher T1 noted that students' transformations manifested across multiple dimensions: "Students are now more willing to ask questions, more diligent in thinking, and show greater enthusiasm for exploring the unknown. Secondly, their hands-on operational skills have improved, and they place increasing emphasis on group collaboration. Finally, their passion for science has grown significantly— before every class, they eagerly ask me, 'What are we going to learn today?'" Teacher T2 also highlighted the enhancement in practical skills: "The most intuitive observation is that the students' hands-on abilities have improved. At first, they struggled with assembling some delicate parts, but by the end of the semester, their practical skills had markedly advanced." Additionally, Teacher T3 noted specific improvements in learning outcomes: "One change that impressed me deeply is that, compared to before, they are more willing to answer questions, and their performance on classroom quizzes has been getting better and better." These responses indicate that participation in the SGs has exerted positive effects on students' classroom engagement, hands-on practical abilities, and academic performance.

(2) Changes in Creative Thinking

Regarding changes in creative thinking, teachers generally agreed that the SGs played an important facilitating role. Teacher T1 observed that students had become bolder and more proactive in their thinking: "I could sense that they were more daring in making attempts, their interest in science learning was gradually increasing, and they were becoming increasingly bold in describing their ideas during the hypothesis-generation phase." Teacher T3 described the changes from the perspective of depth in students' thinking: "From what I have observed, compared with before, these students have begun to show a tendency to get to the bottom of many things." Teacher T2 expressed a similar view: "I believe they have shown some improvement in creative thinking. For example, they are now more inclined to pursue questions relentlessly, which is in fact a manifestation of curiosity development." Teacher T1 also specifically emphasized the development of imagination: "In my view, students' creative thinking has improved to a certain extent. For instance, they are now more likely to propose imaginative and unconventional ideas, which is a sign of imagination development." Taken together, the interviewed teachers consistently agreed that after participating in the SGs, students' curiosity, imagination, challenge-seeking spirit, and tendency toward deep inquiry had all been significantly enhanced.

4.2.2. Analysis of Student Interview Results

(1) Changes in Classroom Performance

When asked about changes in their own science classroom performance before and after the competition, the interviewed students' responses corroborated the teachers' feedback. Student S1 stated, "Before participating in the competition, I actually found science class boring sometimes, and my mind often wandered. But after taking part in this competition, I found science quite interesting. I studied hard, and my grades improved." Student S2 mentioned an increase in confidence and classroom participation: "I used to be really afraid of answering questions, but now, after the competition, I have grown a lot. I can actively answer questions and do classroom presentations." Student S3 added, "After the competition, I think I have become more willing to ask questions and think more in class, and my academic performance has also improved." These statements collectively indicate that participation in the SGs effectively enhanced students' interest in science learning, their confidence in classroom participation, and their willingness to engage in active inquiry.

(2) Changes in Creative Thinking;

To gain a deeper understanding of the changes in each dimension of creative thinking, the researcher interviewed students regarding the four aspects of risk-taking, challenge, imagination, and curiosity. Student S1 explicitly expressed the appeal of challenge and risk-taking to him: "I do enjoy doing challenging and risky things more than before, because it gives me a strong sense of achievement." Student S2 emphasized the emergence of imagination: "I now keep coming up with all kinds of quirky ideas, and I have started to enjoy doing challenging things." Student S3 similarly mentioned a preference for challenging tasks: "I think I now prefer doing challenging things and enjoy participating in competitions. It does not matter if they are somewhat risky." In summary, the student interview results indicate that participation in the SGs significantly enhanced students' intrinsic motivation regarding challenge and risk-taking, while also stimulating their imagination. These findings are highly consistent with the quantitative analysis.

4.2.3. Summary of Interview Findings

Synthesizing the interview results from both teachers and students, the following conclusions can be drawn. First, the SGs exerted a direct positive impact on students' classroom performance, as manifested in enhanced learning interest, increased classroom participation, and improved hands-on and collaborative abilities. Second, as perceived by both teachers and students, the SGs facilitated the development of primary school students' creative thinking, with particularly notable effects in stimulating their challenge-seeking spirit, imagination, and curiosity. These qualitative findings provide rich contextual corroboration for the quantitative results, collectively confirming that the SGs constitute an effective pathway for cultivating creative thinking in primary school students.

4.3. Observational Records of Developmental Characteristics of Students' Creative Thinking Across Stages

To track students' behavioral changes throughout the entire process of SGs training and competition, the researcher, acting as a daily facilitator, conducted accompanying observations and recorded students' performance at various stages in the form of instructional logs. The following stage divisions are synthesized based on the actual training process, with the aim of presenting the general trajectory of students' behavioral changes.

Early Stage of Training (Week 1): In the initial design and fabrication activities, most students exhibited noticeable hesitation and withdrawal. For example, during the paper bridge design session, although the teacher encouraged students to propose their own ideas, the majority were reluctant to express themselves, preferring instead to follow their peers' suggestions or directly accept the teacher's arrangements. In group collaboration, some students lacked communication and coordination skills, occasionally experiencing conflicts over task allocation. These behaviors reflected, to some extent, students' discomfort in open-ended problem-solving contexts, and also fell short of the characteristics required for creative thinking, such as active exploration, independent judgment, and risk-taking.

Middle Stage of Training (Weeks 2–3): Entering the second week, the teacher intentionally introduced structured thinking tools such as brainstorming and trial-and-error methods during training. Students were encouraged to generate as many ideas as possible during the scheme modification phase, and positive feedback was provided for novel ideas, guiding students to extract improvement information from failures. Along with this process, a relatively noticeable behavioral shift was observed: students began to propose their own views more proactively, became more willing to try different approaches when facing difficulties in the fabrication process, and both the frequency of intra-group communication and mutual assistance behaviors increased. The changes observed at this stage suggest that structured creative thinking training may be synchronously associated with enhanced student initiative and increased willingness to collaborate, although the specific mechanisms underlying this relationship require further examination.

Later Stage of Training to Competition Phase (Week 4): Entering the competition preparation and official competition phase, students' performance showed further changes. During the on-site fabrication process, some groups were able to quickly adjust their structural designs in response to actual malfunctions in their work, or employed backward tracing to identify errors in earlier design stages, demonstrating greater flexibility and adaptability compared with their initial performance in the early training stage.

In sum, the above observations indicate that students exhibited behavioral changes throughout the training cycle, progressing from passive dependence to active experimentation and then to flexible adaptation, with different behavioral characteristics prominent at different stages. This trend is consistent with the improvements observed in the scale data, providing contextualized behavioral evidence to support the quantitative findings.

5. Discussion

5.1. Facilitative Effect of the SGs on Primary School Students' Creative Thinking

The finding suggests that the SGs exert a significant facilitative effect on creative thinking in primary school students, a result that aligns with prior research. Zhang et al. (2025) report that school science education environmental factors—including diverse science activities, creative teaching behaviors, and positive teacher-student relationships—exert a positive influence on the development of primary school students' creative thinking. Zhang et al. (2024), in an empirical study employing 3D printing as an instructional medium, also demonstrated that practice-based instructional activity design can significantly enhance primary school students' creative thinking. The present study offers preliminary evidence that these conclusions may also apply to the specific context of the SGs, tentatively suggesting the value of science and technology competition activities in cultivating creative thinking at the primary school level. Furthermore, Han (2024) noted that in primary science instruction, strategies emphasizing hands-on practice, guiding multi-perspective thinking, and encouraging trial and error can effectively stimulate students' curiosity, exploratory drive, and innovative potential. The current findings are broadly consistent with this perspective, providing additional empirical observations that support Han's theoretical proposals.

5.2. The SGs Promote Synergistic Development Across All Dimensions of Creative Thinking

This study analyzed the pre-test and post-test scores across the four dimensions of the Williams Creativity Assessment Packet (risk-taking, challenge, imagination, and curiosity). The results indicated improvements in all dimensions, with increases of 10.9%, 19.5%, 16.3%, and 13.4%, respectively. From the descriptive statistics, the magnitude of increase for the challenge and imagination dimensions was relatively higher. This observation suggests that, while attending to the overall effect of the SGs as a comprehensive intervention, the pronounced changes in challenge and imagination warrant further investigation into their possible mechanisms of action.

From the perspective of activity characteristics, the project design of the SGs is inherently challenging. Students are required to complete design and fabrication tasks under limited resources and time constraints, continuously overcoming technical bottlenecks and optimizing their solutions. Compared with curiosity and risk-taking, which rely more on individual traits and contextual safety, challenge directly corresponds to the difficulty demands of the task itself, and thus its change may be more closely aligned with the intervention activities. An empirical study by Ren and Qi (2020), which used Scratch programming instruction as a vehicle, found that after administering the Williams Creativity Assessment to primary school students, significant improvements were observed across all four dimensions—risk-taking, imagination, curiosity, and challenge—suggesting a close relationship between the provision of challenging tasks and the enhancement of challenge-oriented qualities.

Meanwhile, the improvement in the imagination dimension is closely associated with the complete creative cycle of "conceptualization—prototyping—iterative optimization." Li (2025), through the systematic construction of an educational mapping for primary school students' imagination, elaborated on the practical pathways for fostering imagination from three aspects: curriculum integration, instructional innovation, and field construction, thereby providing a reference framework for understanding the educational supporting conditions for imagination development. In this study, students were required to break away from conventional thinking and propose novel solutions during the design phase, and to make creative adjustments based on functional requirements during the fabrication and refinement phase. This iterative creative practice provided an embodied vehicle for the release and development of imagination.

In addition, the curiosity and risk-taking dimensions also merit attention. Liu and Xu (2024) pointed out that curiosity can be stimulated through mechanisms such as information gaps, prediction errors, novelty, and challenge, and that the creation of science learning contexts is a key pathway for activating these mechanisms. The improvement in the curiosity dimension in this study suggests that the inquiry-based context of the SGs, in which students seek solutions to authentic problems and confront uncertain outcomes, is highly consistent with the aforementioned mechanisms for stimulating curiosity. This provides a theoretical explanation for the observed enhancement in curiosity. Regarding the risk-taking dimension, the study by Ren and Qi (2020) further demonstrated that primary school students' risk-taking tendencies can also be improved through appropriate learning activity design, indicating that an environment that "permits trial and error" plays a positive role in fostering risk-taking. Although the improvement in the risk-taking dimension in this study was relatively modest in magnitude, when considered in light of the activity characteristics, the atmosphere of "permitting trial and error and encouraging exploration" fostered by the SGs may, to some extent, have reduced students' fear of failure and strengthened their behavioral willingness to try new methods and approaches.

Taken together, the activities of the SGs do not merely target any single specific thinking quality, but rather exert a comprehensive influence on the development of all dimensions of creative thinking through the interaction of multiple mechanisms, including challenge-driven tasks, engagement in creative processes, and supportive environmental conditions. This finding provides empirical support for the effectiveness of science and technology competition activities as vehicles for innovation education, and further responds to the call by Zhang and Zhan (2023) for strengthening empirical research on creative thinking cultivation and placing greater emphasis on action research and the translation of cultivation strategies into practical outcomes.

5.3. The SGs Effectively Transform Students' Thinking Patterns Through the "Learning by Doing" Mechanism

Teacher observation records revealed that students underwent noticeable shifts in their thinking patterns throughout the SGs' training process. In the early stage, most students were hesitant and constrained in design and fabrication activities, reluctant to think independently and afraid to express their own views and opinions. Following systematic training in creative thinking strategies such as brainstorming and trial-and-error methods, students gradually demonstrated greater initiative, confidently articulating their own ideas and showing willingness to experiment with novel approaches. By the later stage of training and into the competition phase, students had developed the ability to promptly adjust their plans in response to unexpected situations and to infer sources of error based on problems identified in their products. These changes indicate that students' creative thinking performance exhibited a progressive trajectory throughout the training process, evolving from passive dependence to active experimentation and then to flexible adaptation.

This transformative process can be understood through the practical mechanism of "learning by doing."Qiao et al. (2025), drawing upon constructivist learning theory, proposed that science and technology competitions, functioning as informal learning platforms, can drive students' progressive development from knowledge integration and skill acquisition to innovative practice through a "hierarchical progression + typological complementarity" training model. In this study, students' trajectory of change—from problem identification in the early stage, to skill and thinking training in the middle stage, and then to flexible application in the later stage—is directionally consistent with the capability development sequence described in the above model.

Wang (2024) constructed a "dual helix model" for integrated curriculum design based on "learning by creating," a "flywheel model" for the learning process, and an evaluation model grounded in "learning by creating" learning communities, thereby innovating localized approaches to science and technology education and supporting the early cultivation of science and technology talent at the national level. The findings of this study further suggest that the "learning by doing" practical environment provided by the SGs enables students to transform from passive recipients into active thinkers and enthusiastic explorers. This positive shift in thinking patterns represents an important manifestation of creative thinking development.

6. Conclusions

6.1. Major Findings

This study, involving 13 primary school students from Primary School X who participated in the 6th Zhengzhou Primary and Secondary School SGs, employed multiple methods—including pre- and post-test measurements using the Williams Creativity Assessment, semi-structured interviews, and observational records- to investigate the impact of SGs participation on primary school students' creative thinking. The findings suggest that the SGs significantly facilitated all dimensions of creative thinking in primary school students. These results indicate that the SGs constitute an effective pathway for cultivating creative thinking in primary school students.

6.2. Contributions and Practical Implications

At the theoretical level, this study enriches the research on pathways for cultivating creative thinking in primary school students by incorporating science and technology competition activities into the empirical purview of creative thinking development, thereby providing a new analytical framework and empirical evidence for subsequent related research. At the practical level, the complete creative process through which students engaged—encompassing scheme design, material selection, product fabrication, and iterative optimization within authentic problem-solving contexts — offers a replicable operational paradigm for the concrete implementation of creative thinking cultivation in primary science education.

6.3. Limitations and Future Directions

This study has certain limitations. First, the sample size is relatively small (only 13 participants), which may affect the stability of the findings. Second, the research period is relatively short, covering only a single competition cycle, and thus fails to capture the long-term sustained effects of the SGs. Future research could expand the sample size, introduce a control group design, and conduct longitudinal follow-up studies to more comprehensively and systematically reveal the mechanisms and long-term effects of the SGs on the development of primary school students' creative thinking.

Author Contributions:

Conceptualization, Y.S. and X.L.; methodology, Y.S.; validation, Y.S.; formal analysis, Y.S.; investigation, Y.S.; resources, X.L.; data curation, Y.S.; writing—original draft preparation, Y.S.; writing—review and editing, X.L.; visualization, Y.S.; supervision, X.L.; project administration, X.L.; funding acquisition, X.L. All authors have read and agreed to the published version of the manuscript.

Funding:

This research was funded by Beijing Union University Education Science Research Project "Research on the Design of Chemistry Courses in Science Education Majors" (grant number JK202404).

Institutional Review Board Statement:

Not applicable

Informed Consent Statement:

Not applicable.

Data Availability Statement:

The original contributions presented in this study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author(s).

Acknowledgments:

The authors gratefully acknowledge the valuable suggestions and assistance provided by colleagues in the Department of Science Education during the preparation of this study. We also thank the teachers and students who participated in the data collection for their time and cooperation.

Conflict of Interest:

The authors declare no conflict of interest.

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Appendix

Williams Creativity Assessment Packet

Dear Student,

Hello! This is an exercise to help you understand your own creativity. Please answer the following questions by indicating whether each statement is "Completely True," "Partially True," or "Completely False" for you, and mark a " √ " in the corresponding option in the table after each question. Please answer every item, and do not overthink—go with your first impression, and respond as quickly as possible.

Item	Completely True	Partially True	Completely False
1. I like to guess at things or problems, even if I'm not necessarily right.			
2. I like to carefully observe things I have never seen before in order to understand them in detail.			
3. I like stories that are varied and full of imagination.			
4. When drawing, I like to copy other people's work.			
5. I like to use waste materials (such as old newspapers, bottles, boxes, etc.) to make interesting things.			
6. I like to imagine things I want to know or do.			
7. If I can't finish something in one go, I keep trying until it's done.			
8. I like to refer to various materials in order to gain a broad understanding of things.			
9. I like to do things in the same old ways and don't like to find new methods.			

Item	Completely True	Partially True	Completely False
10. I like to get to the bottom of problems.			
11. I like to do many new things.			
12. I don't make new friends easily.			
13. I like to think about things that would never happen to me.			
14. I like to imagine that one day I could become an artist, musician, or poet.			
15. I sometimes forget other things because of exciting ideas.			
16. I really wish I could live in a space station rather than on Earth.			
17. I think all problems have fixed answers.			
18. I like things that are out of the ordinary.			
19. I often wonder what others are thinking.			
20. I like things described in stories or TV shows.			
21. I like to be with friends and share my ideas with them.			
22. If the last page of a storybook is torn out, I make up a story to complete the ending.			
23. When I grow up, I want to do something that no one has ever thought of before.			
24. Trying new games and activities is fun.			

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https://doi.org/10.71204/xbferv14

Item	Completely True	Partially True	Completely False
25. I don't like being restricted by too many rules.			
26. I like to solve problems, even if there is no correct answer.			
27. There are many things I really want to try out for myself.			
28. I like to sing new songs that nobody knows.			
29. I don't like to express my opinions in front of my classmates.			
30. When I read a novel or watch TV, I like to imagine myself as one of the characters in the story.			
31. I like to imagine what life was like for ancient people.			
32. I often think about writing a new song of my own.			
33. I like to rummage through boxes and cabinets to see what's inside.			
34. When drawing, I really like to change the colors and shapes of various things.			
35. I'm not sure that my views on things are always correct.			
36. Guessing at something first and then seeing if I'm right is a fun approach.			
37. Playing guessing games is fun because I want to know the outcome.			
38. I'm interested in machines and really want to know what they look like inside and how they work.			
39. I like toys that can be taken apart.			

Item	Completely True	Partially True	Completely False
40. I like to think of new ideas, even if they're not useful.			
41. A good article should contain many different opinions and viewpoints.			
42. Finding answers to possible future problems is an exciting thing to do.			
43. I like to try new things just to see what will happen.			
44. When playing games, I usually focus on participating rather than winning.			
45. I like to think about things that people often talk about.			
46. When I see a photo of a stranger, I like to guess what kind of person they are.			
47. I like to browse through books and magazines, but only to get a general idea.			
48. I don't like to explore the various causes of things.			
49. I like to ask questions that others haven't thought of.			
50. Whether at home or at school, I always like to do many interesting things.			