

Enhancing creative thinking skills through project-based learning and SCAMPER: a study in Vietnam

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ABSTRACT

Creative thinking skills (CTS) are essential 21st-century skills for adapting to the rapidly changing world. This study aims to investigate the effectiveness of project-based learning (PBL) and substitute, combine, adapt, modify, put to another use, eliminate, reverse (SCAMPER) in enhancing high school students' CTS, including fluency, flexibility, originality, and usefulness. This quasi-experimental study involved 120 high school students from three classes at a public high school in Vietnam. The study employed a pretest-posttest control group design with one experimental group (n=40) and all two control groups (n=80). The creative engineering design assessment (CEDA) was used. The 15-week intervention involved students in PBL-SCAMPER, while two control groups (n=40 each) followed traditional instruction. One-way analysis of variance (ANOVA) revealed significant improvements in all CTS indicators for the experimental group ($p < 0.05$), with the largest effect on usefulness ($\eta^2 = 0.27$). These findings suggest that the PBL-SCAMPER provides a practical pedagogical framework for developing CTS, warranting broader implementation in high school education.

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1. INTRODUCTION

In the context of a rapidly changing global landscape, creative thinking skills (CTS) are increasingly vital for success in education, work, and life [1], [2]. Enhancing CTS is critical for achieving quality education and responsive youth skill development [3]. However, Programme for International Student Assessment (PISA) 2022 data indicate significant deficiencies in creative thinking proficiency among students globally [4], with 22% of students in Organisation for Economic Co-operation and Development (OECD) countries failing to reach the baseline proficiency level [5]. Systemic barriers further impede CTS development, including overcrowded curricula, limited teaching time, lack of creativity-focused assessments, and insufficient teacher training and resources [6]. Without effective interventions, students may struggle to apply knowledge flexibly in increasingly competitive global contexts [7], [8].

In Vietnam, the examination-oriented education system has traditionally constrained creative thinking and innovation [9], [10]. Teachers often prioritize knowledge transmission over active learning, while existing assessment tools inadequately measure creative thinking [11]. In response, Vietnam's 2018 general education curriculum emphasizes competency-based education, reflecting a national commitment to developing 21st-century skills [12]. Early studies demonstrate that creativity-oriented instructional approaches can enhance CTS in Vietnamese contexts [11]. While previous studies have examined the

benefits of project-based learning (PBL) or substitute, combine, adapt, modify, put to another use, eliminate, reverse (SCAMPER) separately, limited research exists on their integrated effect on high school technology education in Vietnam.

Recent studies have explored PBL-SCAMPER integration in engineering education [13], [14], yet three critical gaps remain. First, research on its application in secondary-level technology education is limited, despite developmental and curricular differences from higher education contexts. Second, its use in collectivist Southeast Asian contexts remains underexplored [9]. Therefore, this study aims to provide empirical evidence on the effectiveness of PBL-SCAMPER integration in enhancing CTS within Vietnamese high school technology education. This study examines the following research question: how does PBL integrated with SCAMPER affect high school students' CTS in technology education?

2. THE COMPREHENSIVE THEORETICAL BASIS

This conceptual framework explores the theoretical foundations of PBL and SCAMPER in fostering CTS within Vietnamese technology education, as shown in Figure 1. It is organized into four sections: i) defining and measuring CTS; ii) the role of technology education in nurturing CTS; and iii) the integration of PBL and SCAMPER as pedagogical tools. This framework serves as the theoretical underpinning for investigating the impact of PBL-SCAMPER on high school students' CTS in Vietnamese education.

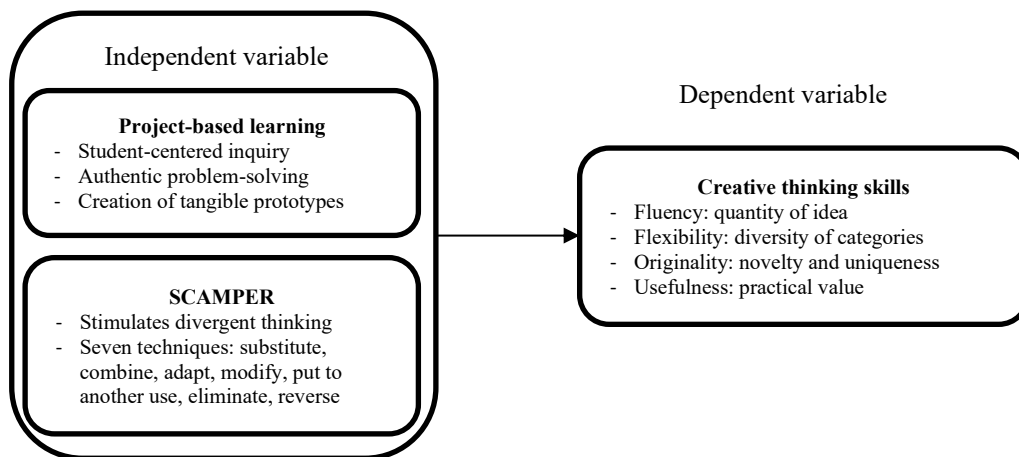


Figure 1. Conceptual framework of PBL-SCAMPER on creative thinking

2.1. Creative thinking skills

Creative thinking is the process of generating solutions that possess both uniqueness and situational value [15]. Unlike general ideation, CTS emphasizes both the generation of diverse categories of solutions and the capacity to propose multiple viable solutions. Moreover, CTS demands originality and practical applicability, which evaluate the effectiveness and feasibility of solutions in addressing a specific problem [16]. To assess CTS, researchers often use four key indicators: fluency, flexibility, originality, and usefulness [17]. Specifically, fluency measures the quantity of ideas generated within a timeframe. Flexibility reflects the diversity of idea categories. Originality captures the novelty and uniqueness of ideas, while usefulness evaluates their practical value and applicability in specific contexts [18]. This study adopts these indicators due to their established reliability and relevance to evaluating CTS in technology education, where students must produce innovative and implementable solutions. While some scholars suggest incorporating cultural and contextual factors to refine CTS assessment [19], this study prioritizes the four-indicator model for its clarity and alignment with educational goals.

2.2. Creative thinking in technology education

Vietnamese technology education prioritizes creative problem-solving and design thinking to support career orientation. It is compulsory at the primary (Grades 3–5) and lower-secondary (Grades 6–9) levels, but becomes elective at the upper-secondary (Grades 10–12) level. Upper-secondary technology education follows a progressive structure: Grade 10 covers foundational knowledge (materials, mechanical structures, and technical drawing); Grade 11 emphasizes applied learning through mechanical processing and practical tool use; Grade 12 focuses on electrical and electronic systems with hands-on circuit practice. This

progressive structure provides a comprehensive foundation for developing creative problem-solving skills and prepares students for increasingly complex creative challenges. Technology education serves as an ideal environment for developing CTS among students. Open-ended tasks and design-based projects help reduce fear of failure while fostering collaboration among learners [20]. Technology education nurtures creativity through iterative ideation and prototyping processes aligned with divergent thinking, while human-centered design promotes empathy and co-creation as foundations of creative inquiry [21].

Studies demonstrated the positive impact of technology education on CTS. For example, at the primary level, students engaged in a STEAM paper-cutting project with BBC micro-bit showed significant improvements in originality, flexibility, and elaboration [22]. This indicates that even early learners can benefit cognitively from technology-integrated activities. At the secondary education level, transdisciplinary modules, such as programming autonomous drones, effectively enhanced both technical proficiency and creativity among Grade 9–10 students when guided by experiential and constructivist learning frameworks [23]. Similarly, in a study with junior high school students in China, higher levels of technology and engineering self-efficacy were found to be positively associated with creative thinking attitudes and perceived value of PBL [24]. While numerous studies have examined creativity enhancement across various levels and subjects in Vietnam [13], research on developing CTS in technology education remains limited. This gap highlights the need for developing CTS through technology education among Vietnamese students.

2.3. PBL and SCAMPER in technology education

Among pedagogical approaches, PBL effectively fosters students' CTS through student-centered inquiry and authentic problem-solving [25]. By emphasizing hands-on, interdisciplinary tasks, PBL enables students to integrate knowledge across multiple domains and apply theoretical concepts to real-world challenges [22]. This approach fosters key CTS indicators such as fluency, flexibility, originality, and elaboration by granting students autonomy in their learning tasks [26]. Furthermore, the highest impact of PBL was recorded at the high school level [25]. PBL also demonstrates significant pedagogical flexibility, allowing implementation across diverse educational contexts [27]. However, students often require additional structured guidance to maximize their creative potential during the ideation phase. SCAMPER offers such guidance through systematic prompts for creative thinking [27]. SCAMPER, an acronym for substitute, combine, adapt, modify, put to another use, eliminate, and reverse [28], encourages learners to tackle problems from different angles, generating innovative solutions while building confidence in creative exploration [28], [29].

Integrating PBL and SCAMPER creates a robust pedagogical framework combining structured creativity and authentic application. This integrated approach enhances CTS by promoting both divergent thinking and structured creativity [14]. While PBL engages students with authentic real-world challenges through learner-centered inquiry and enables the creation of tangible prototypes [30], SCAMPER provides systematic creative prompts to stimulate divergent thinking [31]. Empirical evidence supports their combined effectiveness, with engineering students showing significantly improved fluency, flexibility, originality, and elaboration compared to traditional methods [13]. This integration thus creates a structured yet flexible framework that enhances both creative ideation and practical implementation in technology education contexts.

3. METHOD

This quasi-experimental study utilized a double control group design, employing a pretest-posttest approach [32]. This design was selected to enhance internal validity by isolating the true intervention effect from potential threats, particularly the reactive effect of pretesting. The double-control structure was essential for methodological rigor: control group 1 underwent both pre- and post-measurements to control for extraneous variables. Meanwhile, control group 2 received the post-measurement to quantify and isolate any reactive effect of the pretest on participant performance. This approach ensured that measured gains were genuinely attributable to the intervention rather than to the measurement process itself. All other conditions remained identical across groups.

Participants consisted of 120 eleventh-grade students (25 males, 95 females) from a public high school in Vietnam. Strict inclusion criteria were applied: i) enrollment in the standard technology program; ii) no prior SCAMPER training; and iii) full 15-week participation. To maintain treatment integrity, students missing more than 15% of sessions were excluded from the final analysis. Given fixed classroom structures, convenience sampling was employed using three intact classes ($n=40$ each). A priori power analysis ($\alpha=0.05$, $1-\beta=0.80$, $f=0.30$) confirmed that this sample size was adequate for detecting medium-to-large effects [33]. Furthermore, classes were purposively selected based on comparable baseline performance ($M=7.5-8.2$) and they were taught by the same instructor with over 15 years of experience to minimize instructor-related variability.

This study employed the creative engineering design assessment (CEDA). This framework evaluates the potential for divergent thinking in engineering design among high school students [34]. The Vietnamese

validated version of the instrument was used [35]. CEDA assesses creativity based on four key indicators: fluency, flexibility, originality, and usefulness. Participants had 30 minutes to complete the assessment by describing their design's materials, sizes, modifications, problems addressed, and intended users.

Two trained raters independently scored all responses, with disagreements resolved through discussion. Inter-rater reliability was assessed using Pearson correlations on a random subset of 20 participants. The analysis demonstrated excellent inter-rater agreement across all creativity indicators: fluency ($r=0.995$, $p<0.001$), flexibility ($r=0.991$, $p<0.001$), originality ($r=0.913$, $p<0.001$), and usefulness ($r=0.909$, $p<0.001$). These high coefficients indicate strong consistency in the scoring procedures, thereby supporting the reliability of the measurement.

The PBL-SCAMPER intervention protocol for the experimental group was collaboratively finalized by the researcher and the instructor prior to the semester, encompassing activities and assessment. Implementation fidelity was monitored through weekly meetings throughout the 15-week study to resolve challenges and ensure consistent delivery. The intervention was structured around a five-stage PBL model: driving question, planning, implementation, presentation, and evaluation. The experimental group, divided into 10 teams of 4, worked on the "pushcart design" project, which was integrated with SCAMPER application. Table 1 presents the timeline of the 15-week intervention.

The 15-week PBL-SCAMPER intervention followed a five-stage model, as shown in Table 1. SCAMPER functioned as a cognitive scaffold during the implementation phase (weeks 4-5). After analyzing consumer needs and evaluating existing pushcart designs, student teams systematically applied the seven SCAMPER to deconstruct and reimagine design components. For instance, teams redesigned pushcart handlebars by substituting materials (e.g., bamboo for aluminum) or combining functions. This structured interrogation targets the flexibility and originality dimensions of the CEDA framework, distinguishing it from unstructured brainstorming. The two control groups followed traditional instruction (teacher-led lectures and individual exercises) on the same 15-week timeline with 90-minute sessions. Baseline equivalence was measured via a CEDA pretest in week 1 for the experimental group and CG1, as shown in Table 2. All groups completed the posttest in week 16.

Data were analyzed using R (version 4.4.2). First, we performed an independent t-test for the pre-intervention phase to ensure baseline equivalence between the experimental and control group 1. To evaluate the intervention's effectiveness, a one-way analysis of variance (ANOVA) was conducted to compare posttest scores across the three groups. Significant differences were followed up with a Bonferroni post-hoc test to identify specific pairwise differences. Eta squared (η^2) values were also calculated to assess the practical significance of the intervention. We employed Cohen's d to measure the effect size [36].

Table 1. Intervention timeline

Week	Activity	Tasks
Week 1-2	Orientation and project introduction	Project introduction and group information. Define objectives and scope.
Week 3	Planning	Establish objectives and divide tasks. Identify resources and timeline. Introduce SCAMPER through practice exercises.
Week 4-5	Implementation	Analyze consumer needs and identify target users. Evaluate existing product designs. Apply SCAMPER to generate ideas and initial concepts.
Week 6-7	Material selection	Investigate material properties (metal, alloys, non-metallic materials). Select materials for components.
Week 8-9	Manufacturing methods	Evaluate manufacturing methods. Assess advantages and limitations. Select methods for components.
Week 10	Process planning	Develop manufacturing plans. Define technological processes for machining.
Week 11-13	Construction and testing	Construct a prototype using available materials. Conduct a performance evaluation. Prepare documentation and presentations.
Week 14	Presentation	Present project results and receive feedback
Week 15	Evaluation	Demonstrate the final product and assess performance outcomes.

Table 2. Comparison of the CTS in the pretest

Variable	First control group		Experimental group		T	p	Cohen's d
	M	SD	M	SD			
Fluency	28.08	7.05	27.88	8.38	0.12	0.91	0.03
Flexibility	23.63	5.09	24.53	6.79	-0.67	0.50	-0.15
Originality	8.93	1.56	9.38	2.33	-1.02	0.31	-0.23
Usefulness	11.05	2.01	10.48	2.42	1.16	0.25	0.26

Note: Independent samples t-test. No significant differences between the two groups were observed

4. RESULTS AND DISCUSSION

To address research question, one-way ANOVAs were conducted to compare CTS outcomes across the three groups. The results revealed that the experimental group significantly outperformed both control groups across all four CTS indicators ($p < 0.05$), as shown in Table 3. Fluency showed a small to medium effect ($F(2,117)=4.76$, $p=0.01$, $\eta^2=0.08$), flexibility demonstrated a medium effect ($F(2,117)=6.73$, $p < 0.001$, $\eta^2=0.10$), and originality exhibited a medium effect ($F(2,117)=5.75$, $p < 0.001$, $\eta^2=0.09$). The most substantial impact was observed for usefulness ($F(2,117)=21.61$, $p < 0.001$, $\eta^2=0.27$). According to Cohen [36] guidelines, this η^2 value represents a large practical effect size, indicating that the intervention successfully enabled participants to generate ideas that were not only novel but also highly practical and applicable. Notably, no significant differences emerged between control groups 1 and 2 across any indicator, confirming that pretesting did not influence outcomes.

Table 3. One-way ANOVA results post-intervention CTS

Variables	Control 1		Control 2		Experimental		F	df	p	η^2
	M	SD	M	SD	M	SD				
Fluency	29.10	11.11	28.90	9.09	35.35	5.88	4.76	(2, 117)	0.01	0.08
Flexibility	24.60	8.69	23.70	6.94	29.10	5.20	6.73	(2, 117)	0.00	0.10
Originality	9.30	2.71	9.20	2.65	11.10	3.08	5.75	(2, 117)	0.00	0.09
Usefulness	11.80	2.76	11.90	2.15	14.95	2.33	21.61	(2, 117)	0.00	0.27

Note: $p < 0.001$ is displayed as 0.00

Bonferroni post-hoc comparisons were conducted to pinpoint specific group differences, as shown in Table 4. The analysis confirmed that the experimental group scored significantly higher on all four creative thinking measures compared to both control groups. The largest differences emerged for usefulness, with the experimental group outperforming control group 1 ($M_{diff}=3.03$, $p < 0.001$) and control group 2 ($M_{diff}=3.15$, $p < 0.001$). Importantly, no significant differences were observed between the two control groups on any indicator, confirming that the pretesting procedure did not inflate or deflate performance in control group 1. This consistent pattern of superior performance in the experimental group provides robust empirical support for the effectiveness of the PBL-SCAMPER intervention in fostering CTS.

Table 4. Bonferroni post-hoc comparisons of CTS outcomes

Variables	Contrast	Mean diff.	95% CI low	95% CI high	Adj. p-value
Fluency	Con 1-Con 2	0.20	-4.55	4.95	0.99
	Exp-Con 1	5.45	0.70	10.20	0.02
	Exp-Con 2	5.25	0.50	10.0	0.02
Flexibility	Con1-Con 2	0.90	-2.86	4.66	0.84
	Exp-Con 1	5.43	1.66	9.19	0.00
	Exp-Con 2	4.53	0.76	8.29	0.01
Originality	Con1-Con 2	0.10	-1.40	1.60	0.98
	Exp-Con 1	1.90	0.40	3.40	0.00
	Exp-Con 2	1.80	0.40	3.30	0.01
Usefulness	Con 1-Con 2	-0.13	-1.41	1.16	0.97
	Exp-Con 1	3.03	1.74	4.31	0.00
	Exp-Con 2	3.15	1.86	4.44	0.00

Note: Exp=experimental group; Con=control group

The strong impact on usefulness aligns with Charyton [18] emphasis on novelty and functionality in technological creativity. This pronounced effect can be explained by several factors. First, the use of the CEDA instrument, which explicitly emphasizes practical application, may have inherently biased the outcome compared to tools like the Torrance tests of creative thinking (TTCT). Second, high school students, often unaccustomed to open-ended design tasks, might gravitate towards functional ideas due to their cognitive developmental stage [33]. Third, group-face motivation emerges as a critical factor in collaborative learning [33]. The project's inherent collaborative nature, such as in the "pushcart design" project, likely spurred students to uphold their team's reputation by ensuring the proposed design was practical and functional. The safe, psychologically affirming environment fostered by PBL teamwork and SCAMPER's structured guidance was crucial. This environment allowed students to focus on generating applicable solutions by minimizing the fear of personal or group critique. Although the PBL-SCAMPER intervention produced statistically significant gains across all four CTS indicators ($p < 0.05$), the effect sizes for fluency ($\eta^2=0.08$) and flexibility ($\eta^2=0.09$) indicated only moderate practical significance. This pattern can be attributed to two interdependent factors.

First, social-psychological constraints, particularly the suppression of divergent ideas among some students due to concerns about public image and passive participation [37], must be addressed when designing collaborative tasks. This aligns with findings that students operating within Vietnam's collectivist culture often exhibit hesitancy in voicing diverse or unconventional ideas to maintain social harmony and preserve group cohesion "saving face" [33]. In collaborative tasks like the "pushcart design" project, this cultural tendency may have led participants to prioritize group consensus over the extensive exploration of possibilities required for high fluency and flexibility. Second, students experienced cognitive limitations related to a premature transition into convergent thinking. Since fluency and flexibility are indicators strongly tied to the initial, divergent stages of the design process [28], this premature cognitive shift resulted in a restricted volume and variety of generated ideas. This difficulty, combined with the characteristically slower ideation pace of less creative learners [14], collectively attenuated the overall practical effect size for both fluency and flexibility.

These findings indicate that while the PBL-SCAMPER framework is highly effective for promoting certain CTS indicators, it exhibits limitations as a standalone strategy. The structured nature of SCAMPER, compounded by the contextual factors discussed, may be insufficient to fully cultivate the robust, free-flowing ideation required for fluency and flexibility. This highlights the critical need to integrate complementary pedagogical approaches, such as generative artificial intelligence tools [38]. Ultimately, achieving a comprehensive and holistic enhancement of all CTS dimensions necessitates integrating such complementary strategies alongside the PBL-SCAMPER framework.

Despite the moderate effects on fluency and flexibility, the significant impact on usefulness offers substantial insights. While previous studies have often prioritized originality [13] or fluency [37], our results underscore the capacity of the PBL-SCAMPER model to effectively enhance the practical application dimension of CTS. This outcome is highly relevant to Vietnam's 2018 curriculum reform, which explicitly prioritizes real-world applications and problem-solving over abstract ideation [39]. These findings contribute valuable empirical data to the literature by demonstrating how structured creativity frameworks can effectively foster practical ideation within teacher-guided educational contexts in Vietnam.

5. CONCLUSION

This study demonstrates that integrating PBL with SCAMPER significantly enhances CTS among high school technology students. The experimental group outperformed control groups across all indicators, notably in usefulness, which showed the most substantial improvement ($\eta^2=0.27$, $p<0.05$). This reinforces the efficacy of structured, collaborative pedagogy in fostering equitable creativity. The results highlight PBL-SCAMPER's potential within Vietnam's technology education. To leverage this, educators should adopt real-world projects and professional development should focus on facilitating SCAMPER's divergent thinking prompts. These insights support educational transitions toward 21st-century frameworks, bridging traditional instruction and innovation to better prepare students for global competition. Despite these contributions, the study's limitations include convenience sampling, single-school context, which may affect generalizability. Future research should employ randomized trials across multiple schools grade levels, and subject areas would improve the generalizability of the findings.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Nguyen Thi Phuong Thanh	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓
Le Huong Hoa		✓				✓		✓	✓	✓	✓	✓		

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declared that there were no potential conflicts of interest.

INFORMED CONSENT

Informed consent was obtained from all participating students regarding their involvement in the study. Approval to conduct the experiment was secured from the administration of the collaborating high school.

DATA AVAILABILITY

The datasets generated during and analyzed during the current study are available from the corresponding author, [LHH], on reasonable request.





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