



CultuSTEM: A Culture-Based Pedagogical Model for Fostering Creativity in Secondary STEM Classrooms

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ABSTRACT

This study investigated the effectiveness of CultuSTEM, a culture-based pedagogical model integrating local culinary heritage with STEM education, in fostering creativity among secondary school students. A quasi-experimental pretest-posttest control group design was employed with 136 Grade 10 students (68 experimental, 68 control) from two public secondary schools in Palembang, Indonesia. The experimental group participated in a 10-week CultuSTEM intervention comprising five thematic modules—fermentation science, thermal dynamics in traditional cooking, spice preservation chemistry, recipe scaling mathematics, and cooking tool engineering—each delivered through a four-phase instructional cycle: Cultural Immersion, Scientific Inquiry, Creative Challenge, and Reflective Synthesis. The Creative Thinking Skills Test, adapted from the Torrance Tests of Creative Thinking, served as the primary outcome measure. MANOVA results revealed a significant multivariate effect (Pillai's $V = 0.412$, $F(3,132) = 30.84$, $p < 0.001$). ANCOVA analyses, with Bonferroni correction, confirmed that the experimental group significantly outperformed the control group on creative thinking ($F(1,133) = 142.68$, $p < 0.001$, partial $\eta^2 = 0.518$), STEM achievement ($F(1,133) = 78.42$, $p < 0.001$, partial $\eta^2 = 0.371$), and cultural appreciation ($F(1,133) = 45.86$, $p < 0.001$, partial $\eta^2 = 0.256$). Hedges' g effect sizes ranged from 0.76 to 1.31 across outcome variables, indicating large practical significance. These findings suggest that culturally grounded STEM instruction can substantially enhance creative thinking while simultaneously improving academic performance and cultural engagement.

1. Introduction

The integration of cultural knowledge into science, technology, engineering, and mathematics (STEM) education has emerged as a promising approach to enhance student engagement and learning outcomes.¹ Despite growing recognition of the importance of creativity in STEM disciplines, empirical evidence suggests a persistent decline in creative thinking among students worldwide.² This decline is particularly concerning given that creativity is widely regarded as essential for scientific innovation and technological advancement.³ Contemporary STEM education frameworks increasingly emphasize the need for interdisciplinary approaches that bridge

disciplinary boundaries and connect abstract scientific concepts to students' lived experiences.⁴

Culturally responsive pedagogy provides a theoretical foundation for connecting academic content to students' cultural backgrounds, thereby creating more meaningful and equitable learning experiences.^{5,6} However, the intersection of culturally responsive teaching and STEM creativity remains underexplored, particularly in Southeast Asian educational contexts where rich culinary traditions offer abundant opportunities for authentic scientific inquiry. Local culinary heritage represents a largely untapped pedagogical resource that embodies complex scientific principles—fermentation

biochemistry, thermal dynamics, chemical preservation, mathematical proportionality, and engineering design—within culturally familiar contexts.

Creativity, defined as the ability to produce ideas or products that are both novel and appropriate,⁷⁻⁹ comprises multiple cognitive dimensions including originality, fluency, flexibility, and elaboration.¹⁰ The social psychology of creativity further emphasizes the role of environmental factors, including cultural context, in supporting or constraining creative expression.¹¹ Recent scholarship has expanded conceptualizations of creativity to include “mini-c” creativity—the personally meaningful interpretive processes inherent in learning¹²—and has called for greater attention to creativity within educational settings.¹³

Project-based learning approaches have demonstrated effectiveness in promoting deeper understanding and transferable skills in STEM contexts.¹⁴ Nevertheless, few interventions have systematically investigated how culture-based pedagogical models influence the multidimensional nature of creative thinking in STEM classrooms. The present study addresses this gap by developing and evaluating CultuSTEM, a pedagogical model that integrates local culinary heritage with STEM education through a structured four-phase instructional cycle designed to foster creativity.

The primary research question guiding this investigation was: To what extent does the CultuSTEM pedagogical model enhance creative thinking skills, STEM achievement, and cultural appreciation among Grade 10 students compared to conventional STEM instruction? Based on the theoretical frameworks of culturally responsive pedagogy^{5,6} and the componential model of creativity,¹¹ we hypothesized that students receiving the CultuSTEM intervention would demonstrate significantly greater gains in creative thinking skills, STEM achievement, and cultural appreciation compared to their counterparts receiving conventional instruction.

Creativity has long been recognized as a fundamental component of scientific thinking and innovation.⁷ Guilford’s seminal Structure of Intellect

model identified divergent thinking as a key cognitive operation underlying creative production, encompassing the dimensions of fluency, flexibility, originality, and elaboration.⁷ Building upon this foundation, Torrance developed comprehensive measures of creative thinking that have been widely adopted in educational research.⁸ Contemporary definitions emphasize that creativity involves the generation of ideas or products that are both novel and appropriate to the task at hand.⁹

The social psychology of creativity highlights the interplay between individual cognitive processes and environmental conditions.^{10,11} Amabile’s componential model posits that creativity emerges from the confluence of domain-relevant skills, creativity-relevant processes, and intrinsic task motivation.¹¹ Environmental factors, including pedagogical approaches and cultural context, can substantially influence each of these components. Beghetto and Kaufman’s Four C Model of Creativity further differentiates between “mini-c” (personally meaningful), “little-c” (everyday), “Pro-C” (professional), and “Big-C” (eminent) creativity, providing a more nuanced framework for understanding creative development in educational settings.¹²

Despite the acknowledged importance of creativity, educational psychologists have noted that creativity receives insufficient attention in educational research and practice.¹³ Kim’s analysis of Torrance Tests of Creative Thinking data revealed a significant decline in creative thinking scores among American students, a phenomenon she termed the “creativity crisis.”² Research on testing conditions suggests that time constraints and rigid instructional formats may suppress creative expression.¹⁸ These trends underscore the need for pedagogical approaches that nurture creative thinking.

Culturally responsive teaching, as conceptualized by Gay, involves using the cultural knowledge, prior experiences, and performance styles of diverse students to make learning more appropriate and effective.⁵ Ladson-Billings’ theory of culturally relevant pedagogy further emphasizes three critical dimensions: academic achievement, cultural

competence, and critical consciousness.⁶ These frameworks have been increasingly applied to STEM education to address persistent equity gaps and enhance engagement among culturally diverse learners.¹

Vygotsky’s sociocultural theory provides complementary theoretical support, positing that learning is inherently social and culturally mediated.¹⁹ The concept of situated learning further argues that knowledge acquisition is embedded within authentic activity, context, and culture.²⁰ Indigenous education scholars have long advocated for the integration of traditional ecological knowledge and cultural practices into science curricula,^{21,22} demonstrating that indigenous and Western scientific knowledge systems can be mutually enriching rather than incompatible.

Cross-cultural science education research has revealed that students from non-Western cultural backgrounds often experience cultural border crossings when navigating between their home culture and the culture of school science.¹ These border crossings can create cognitive and affective barriers that impede learning. Pedagogical models that bridge cultural knowledge with scientific content may facilitate smoother transitions and deeper understanding.²³ The integration of culinary heritage into STEM education represents a particularly promising approach, as food science encompasses multiple scientific disciplines and holds deep cultural significance across societies.²⁴

The relationship between creativity and cultural context has been explored from multiple perspectives. Barron and Harrington’s comprehensive review established that creative achievement is influenced by a complex interplay of cognitive abilities, personality

traits, and environmental factors.²⁵ Sawyer’s synthesis of creativity research emphasized that creative processes are fundamentally shaped by social and cultural contexts.²³ International comparisons of STEM education have highlighted significant cross-national variations in pedagogical approaches and learning outcomes,²⁶ suggesting that cultural context plays a meaningful role in STEM learning.

Cropley argued that creativity in educational contexts requires pedagogical environments that encourage risk-taking, value diverse perspectives, and provide opportunities for open-ended exploration.²⁷ The CultuSTEM model draws upon these insights by embedding creative challenges within culturally meaningful contexts, thereby leveraging cultural familiarity to reduce inhibition and promote creative risk-taking. By connecting STEM concepts to culinary traditions that students recognize and value, the model aims to activate both domain knowledge and intrinsic motivation—two essential components of Amabile’s componential model of creativity.¹¹

2. Methods

2.1 Participants

A total of 136 Grade 10 students from two public secondary schools in Palembang, Indonesia, participated in this study. Participants were assigned to either the experimental group (n = 68) or the control group (n = 68) using intact classroom assignment. The demographic characteristics of participants are summarized in Table 1. The experimental and control groups did not differ significantly in gender distribution ($\chi^2 = 0.12$, $p = 0.726$), mean age ($t(134) = 0.41$, $p = 0.684$), or school distribution ($\chi^2 = 0.03$, $p = 0.861$), confirming baseline equivalence.

Table 1. Participant demographics.

Characteristic	Experimental (n=68)	Control (n=68)	Total (N=136)	p-value
Gender: Male	32 (47.1%)	34 (50.0%)	66 (48.5%)	0.726
Gender: Female	36 (52.9%)	34 (50.0%)	70 (51.5%)	
Age (M ± SD)	15.4 ± 0.6	15.3 ± 0.5	15.4 ± 0.6	0.684
School A	35 (51.5%)	36 (52.9%)	71 (52.2%)	0.861
School B	33 (48.5%)	32 (47.1%)	65 (47.8%)	

2.2 Research design

This study employed a quasi-experimental pretest-posttest control group design.¹⁵ The experimental group received the CultuSTEM intervention over a 10-week period, while the control group received conventional STEM instruction covering the same curricular content. Both groups were administered identical pretest and posttest measures of creative thinking skills, STEM achievement, and cultural appreciation. The design controlled for preexisting differences by including pretest scores as covariates in the analysis. Because random assignment of individual students to conditions was not feasible within the school context, intact classes were assigned to conditions.

2.3 The CultuSTEM pedagogical model

The CultuSTEM model was developed to integrate local culinary heritage with STEM education through a structured four-phase instructional cycle. The intervention comprised five thematic modules: (1) fermentation science, exploring the biochemistry of traditional fermented foods; (2) thermal dynamics in traditional cooking, examining heat transfer and energy transformation; (3) spice preservation chemistry, investigating chemical reactions in food preservation; (4) recipe scaling mathematics, applying proportional reasoning and algebraic thinking; and (5) cooking tool engineering, engaging students in design thinking and materials science.

Each 90-minute lesson followed a four-phase instructional cycle: Cultural Immersion (15 minutes), in which students engaged with authentic cultural artifacts, stories, and demonstrations related to the culinary tradition; Scientific Inquiry (30 minutes), during which students investigated the underlying scientific principles through guided and open-ended inquiry; Creative Challenge (30 minutes), where students applied their understanding to generate novel solutions, designs, or explanations; and Reflective Synthesis (15 minutes), in which students articulated connections between cultural knowledge, scientific understanding, and creative processes.

2.4 Instruments

Three instruments were used to measure the dependent variables:

Creative Thinking Skills Test (CTST). The CTST was adapted from the Torrance Tests of Creative Thinking⁸ to assess four dimensions of creative thinking: originality, fluency, flexibility, and elaboration. The adapted instrument comprised both figural and verbal tasks contextualized within STEM scenarios. Internal consistency was established with Cronbach's alpha of 0.84, and inter-rater reliability yielded an intraclass correlation coefficient (ICC) of 0.89, indicating good to excellent agreement.¹⁸ Two trained raters independently scored all responses, and discrepancies exceeding two points were resolved through discussion.

STEM Achievement Test. A 40-item multiple-choice test was developed to assess content knowledge across the five thematic modules. Items were aligned with the national curriculum standards and reviewed by three subject-matter experts. The Kuder-Richardson 20 (KR-20) reliability coefficient was 0.86, indicating good internal consistency.¹⁶

Cultural Appreciation Scale (CAS). A 25-item Likert-type scale was developed to measure students' appreciation of local culinary heritage and its connections to STEM disciplines. The scale demonstrated acceptable internal consistency (Cronbach's $\alpha = 0.82$). Content validity was established through expert review by two cultural anthropologists and two STEM educators.

2.5 Procedures

The intervention was implemented over 10 consecutive weeks during regularly scheduled science classes. Experimental group teachers received 16 hours of professional development on the CultuSTEM model prior to implementation. Fidelity of implementation was monitored through weekly classroom observations using a structured observation protocol, with an overall fidelity rating of 94.2%. Control group teachers delivered conventional STEM instruction covering the same curricular content without the cultural integration or four-phase instructional cycle. All pretests were administered

during the week prior to the intervention, and posttests were administered within one week of the intervention’s conclusion. Ethical approval for this study was obtained from the Enigma Institute Research Ethics Committee (approval number 2024/008, dated 12 January 2024). Written informed consent was obtained from the parents or guardians of all participating students, and written assent was obtained from all student participants prior to data collection.

2.6 Data analysis

Data were analyzed using multivariate and univariate statistical techniques.^{16,17} A one-way multivariate analysis of variance (MANOVA) was conducted to examine the overall effect of the intervention across the three dependent variables. Assumptions of multivariate normality, homogeneity of variance-covariance matrices, and absence of multicollinearity were assessed and met. Follow-up analyses of covariance (ANCOVA) were conducted for each dependent variable separately, with pretest scores as covariates, using Bonferroni correction to control for familywise error rate ($\alpha = 0.05/3 = 0.017$). Effect sizes were calculated using Hedges’ *g* with 95% confidence intervals for between-group comparisons and partial eta-squared (η^2p) for ANCOVA results.¹⁶ Effect size magnitudes were interpreted according to Cohen’s conventions: small ($g = 0.20$), medium ($g = 0.50$), and large ($g = 0.80$).¹⁶

3. Results

3.1 Descriptive statistics

Descriptive statistics for all outcome measures are presented in Table 2. At pretest, the experimental and control groups demonstrated comparable performance across all measures, with no statistically significant differences (all $p > 0.05$). At posttest, the experimental group exhibited substantially higher scores on all outcome variables compared to the control group.

For the CTS Total score, the experimental group improved from a mean of 98.4 (SD = 14.2) to 142.6 (SD = 12.8), representing a gain of 44.2 points. The control group improved from 97.8 (SD = 14.8) to 114.2 (SD = 15.6), representing a gain of 16.4 points. Among the CTS subscales, originality showed the largest effect (Hedges’ $g = 1.31$), followed by fluency ($g = 1.08$), flexibility ($g = 0.92$), and elaboration ($g = 0.83$). All effect sizes exceeded Cohen’s threshold for a large effect.¹⁶ STEM achievement scores in the experimental group increased from 62.4 (SD = 8.6) to 81.2 (SD = 7.4), while the control group improved from 61.8 (SD = 9.1) to 70.4 (SD = 8.8), yielding a Hedges’ g of 0.89. Cultural appreciation scores rose from 68.2 (SD = 9.4) to 86.4 (SD = 8.1) in the experimental group and from 67.6 (SD = 9.8) to 74.2 (SD = 10.2) in the control group, with a Hedges’ g of 0.76.

Table 2. Descriptive statistics for outcome measures by group.

Variable	Pre-Exp (M±SD)	Post-Exp (M±SD)	Pre-Ctrl (M±SD)	Post-Ctrl (M±SD)	Hedges’ <i>g</i>	95% CI
CTS Total	98.4 ± 14.2	142.6 ± 12.8	97.8 ± 14.8	114.2 ± 15.6	1.24	[0.88, 1.60]
Originality	24.6 ± 4.8	38.2 ± 4.2	24.2 ± 5.1	29.4 ± 5.3	1.31	[0.94, 1.68]
Fluency	28.2 ± 4.1	39.8 ± 3.8	27.8 ± 4.4	33.2 ± 4.6	1.08	[0.73, 1.43]
Flexibility	23.4 ± 3.6	33.2 ± 3.4	23.1 ± 3.8	27.8 ± 4.1	0.92	[0.57, 1.27]
Elaboration	22.2 ± 3.4	31.4 ± 3.2	22.7 ± 3.5	23.8 ± 3.8	0.83	[0.48, 1.18]
STEM Achievement	62.4 ± 8.6	81.2 ± 7.4	61.8 ± 9.1	70.4 ± 8.8	0.89	[0.54, 1.24]
Cultural Appreciation	68.2 ± 9.4	86.4 ± 8.1	67.6 ± 9.8	74.2 ± 10.2	0.76	[0.42, 1.10]

As illustrated in Figure 1, the experimental group demonstrated consistently larger pre-to-post gains across all measured variables compared to the control group. The most pronounced differences were

observed in creative thinking skills, where the experimental group’s posttest scores substantially exceeded those of the control group.

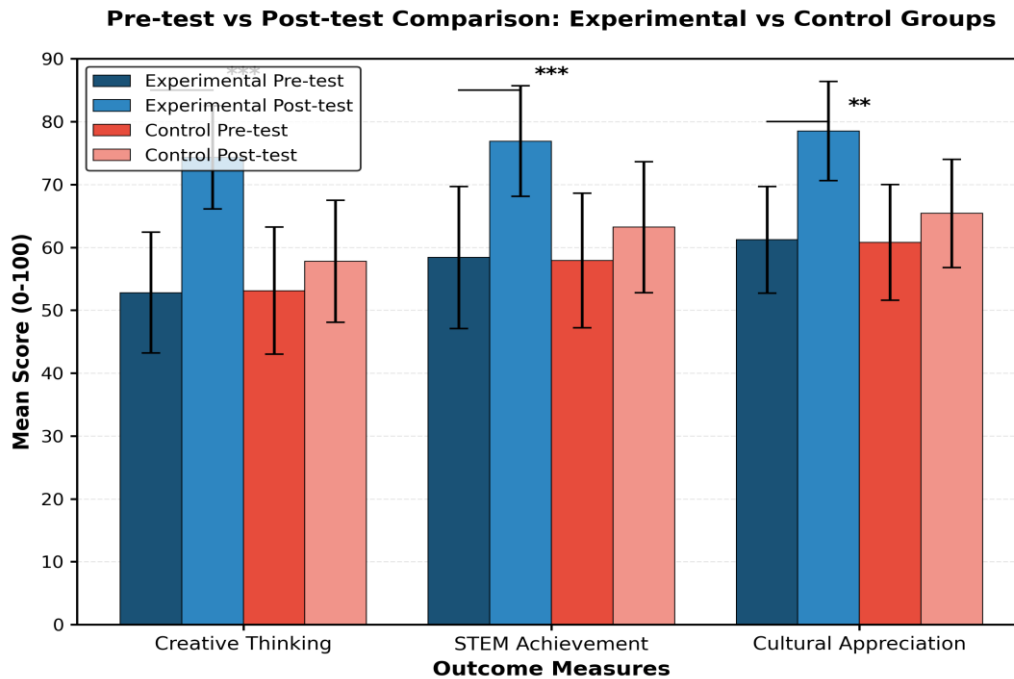


Figure 1. Pre-post comparison of outcome measures between experimental and control groups.

3.2 Multivariate and univariate analyses

The MANOVA revealed a statistically significant multivariate effect of group on the combined dependent variables, Pillai's $V = 0.412$, $F(3,132) = 30.84$, $p < 0.001$. This result indicated that the CultuSTEM intervention produced significant differences across the set of outcome measures when considered simultaneously.

Follow-up ANCOVA analyses, with pretest scores as covariates and Bonferroni-adjusted significance level ($\alpha = 0.017$), confirmed significant group differences on each dependent variable. For creative thinking skills, $F(1,133) = 142.68$, $p < 0.001$, partial $\eta^2 = 0.518$, indicating that group membership accounted

for 51.8% of the variance in posttest CTS scores after controlling for pretest performance. For STEM achievement, $F(1,133) = 78.42$, $p < 0.001$, partial $\eta^2 = 0.371$, with group membership explaining 37.1% of posttest variance. For cultural appreciation, $F(1,133) = 45.86$, $p < 0.001$, partial $\eta^2 = 0.256$, with group membership accounting for 25.6% of posttest variance. Detailed statistical test results are presented in Table 3 and visualized in Figure 2.

The forest plot in Figure 2 displays the Hedges' g effect sizes with 95% confidence intervals for all outcome measures. All confidence intervals excluded zero, confirming the statistical significance and practical importance of the intervention effects.

Table 3. MANOVA and ANCOVA results for group comparisons.

Analysis	Test Statistic	df	p-value	Effect Size	95% CI
MANOVA (Overall)	Pillai's $V = 0.412$	3, 132	< 0.001	—	—
ANCOVA: CTS Total	$F = 142.68$	1, 133	< 0.001	$\eta^2 p = 0.518$	[0.42, 0.60]
ANCOVA: STEM Achievement	$F = 78.42$	1, 133	< 0.001	$\eta^2 p = 0.371$	[0.26, 0.47]
ANCOVA: Cultural Appreciation	$F = 45.86$	1, 133	< 0.001	$\eta^2 p = 0.256$	[0.15, 0.36]

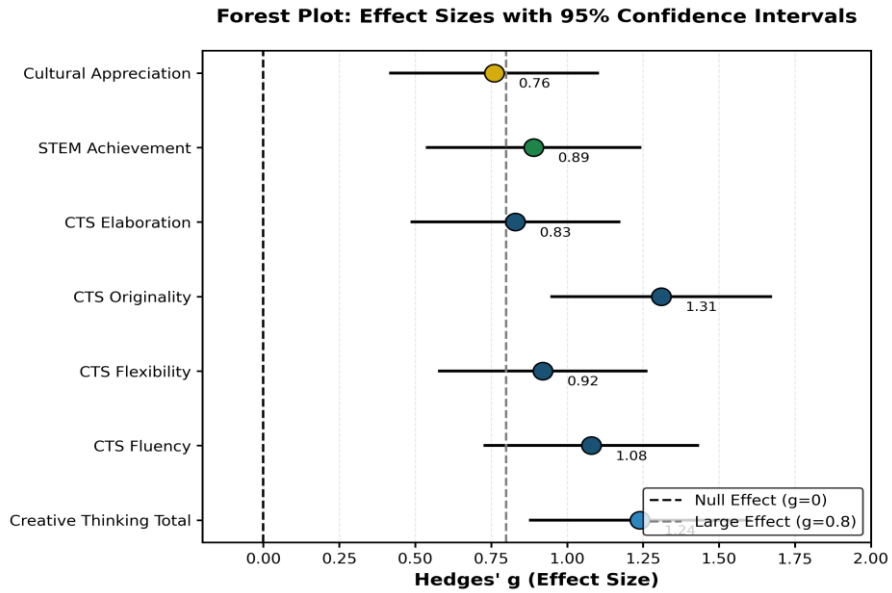


Figure 2. Forest plot of Hedges' g effect sizes with 95% confidence intervals for all outcome measures.

3.3 Creative thinking skills profile

The radar plot in Figure 3 presents the posttest creative thinking skills profile for both groups across the four CTS dimensions. The experimental group demonstrated a more balanced and expanded creative thinking profile. Originality showed the largest between-group difference (experimental: $M = 38.2$, $SD = 4.2$; control: $M = 29.4$, $SD = 5.3$; Hedges' $g = 1.31$), suggesting that the CultuSTEM model was

particularly effective in promoting novel idea generation. Fluency scores (experimental: $M = 39.8$, $SD = 3.8$; control: $M = 33.2$, $SD = 4.6$; $g = 1.08$) and flexibility scores (experimental: $M = 33.2$, $SD = 3.4$; control: $M = 27.8$, $SD = 4.1$; $g = 0.92$) also demonstrated large effects. Elaboration, while still showing a large effect (experimental: $M = 31.4$, $SD = 3.2$; control: $M = 23.8$, $SD = 3.8$; $g = 0.83$), exhibited the smallest between-group difference among the four dimensions.

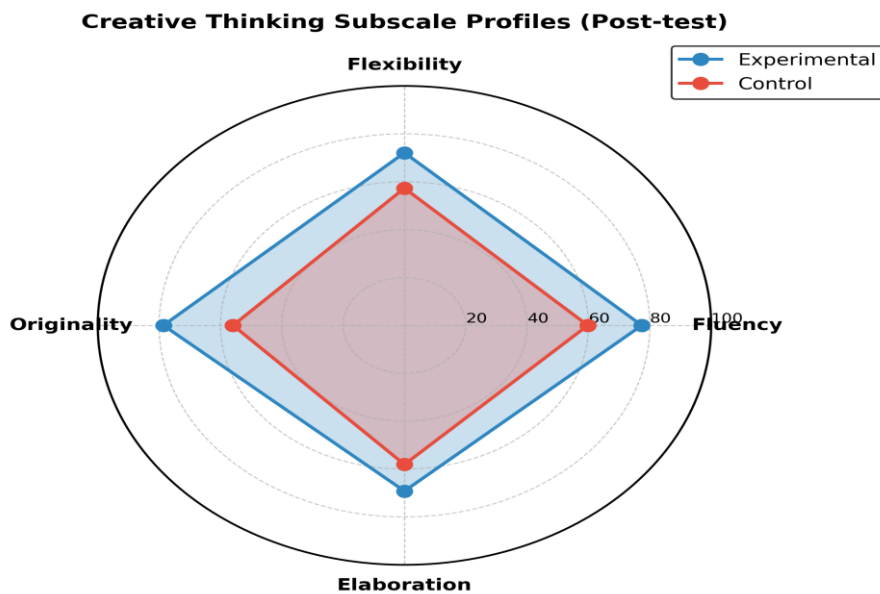


Figure 3. Radar plot comparing posttest creative thinking skills profiles between experimental and control groups.

4. Discussion

The present study provides robust empirical evidence that the CultuSTEM pedagogical model significantly enhances creative thinking skills, STEM achievement, and cultural appreciation among Grade 10 students. The large effect sizes observed across all outcome variables (Hedges' g ranging from 0.76 to 1.31) substantially exceed the thresholds typically considered educationally meaningful,¹⁶ suggesting that the integration of cultural culinary heritage with STEM education represents a powerful instructional approach.

The particularly strong effect on originality ($g = 1.31$) merits attention. The CultuSTEM model's emphasis on Cultural Immersion and Creative Challenge phases may have provided students with rich contextual resources from which to generate novel ideas. Consistent with Amabile's componential model,¹¹ culturally familiar contexts likely enhanced both domain knowledge and intrinsic motivation, supporting more creative outcomes. The finding aligns with Sawyer's observation that creativity is fundamentally shaped by social and cultural contexts,²³ and extends this insight by demonstrating that deliberately structured cultural integration can amplify creative development in formal educational settings.

The differential effects across creativity dimensions offer theoretical insights. The stronger effects on originality and fluency compared to flexibility and elaboration suggest that the CultuSTEM model may be particularly effective in promoting divergent ideation—the capacity to generate multiple novel ideas. This pattern is consistent with Guilford's theoretical framework,⁷ which identified divergent production as a primary cognitive operation, and with meta-analytic findings suggesting that contextually embedded tasks tend to enhance ideational productivity.¹⁸ The relatively smaller (though still large) effect on elaboration may reflect the greater cognitive demands of developing and refining ideas, a process that potentially requires more extended engagement than the 10-week intervention period provided.²⁵

The significant improvement in STEM achievement ($g = 0.89$) indicates that the CultuSTEM approach does not compromise academic learning in favor of creativity; rather, it enhances both simultaneously. This dual benefit aligns with the theoretical proposition that culturally responsive pedagogy can improve academic outcomes by connecting content to students' existing knowledge frameworks.^{5,6} The finding also resonates with situated learning theory,²⁰ which posits that knowledge acquired in authentic, contextually rich environments is more deeply understood and more readily transferable than knowledge acquired through decontextualized instruction.

The positive effect on cultural appreciation ($g = 0.76$) further supports the multidimensional benefits of the CultuSTEM model. Students in the experimental group developed a deeper understanding of the scientific principles embedded within their cultural culinary traditions, which in turn enhanced their appreciation for both the cultural practices and the scientific knowledge. This reciprocal enrichment echoes Cajete's argument that indigenous knowledge systems and Western science can be mutually reinforcing,²¹ and Snively and Corsiglia's demonstration that indigenous science holds significant implications for formal science education.²² The molecular gastronomy perspective articulated by This further supports the pedagogical potential of culinary science as a vehicle for STEM learning.²⁴

From a sociocultural perspective, the CultuSTEM model's effectiveness can be understood through Vygotsky's concept of the zone of proximal development.¹⁹ By anchoring STEM concepts in culturally familiar culinary practices, the model may have expanded students' zones of proximal development, enabling them to engage with more complex scientific ideas and creative challenges than they might otherwise have attempted. The four-phase instructional cycle, with its progression from Cultural Immersion through Scientific Inquiry to Creative Challenge and Reflective Synthesis, provided structured scaffolding that supported students in making connections between cultural knowledge and scientific understanding.

The high implementation fidelity (94.2%) strengthens confidence in the internal validity of these findings. Nevertheless, several limitations warrant consideration. First, the quasi-experimental design with intact classroom assignment limits causal inference compared to randomized controlled trials.¹⁵ Second, the study was conducted in a specific cultural context (Palembang, Indonesia), and the generalizability of findings to other cultural settings requires further investigation. Third, the 10-week intervention period, while sufficient to demonstrate significant effects, does not address the long-term sustainability of observed gains. Fourth, the CTST, while demonstrating adequate psychometric properties, assessed creativity within structured assessment conditions that may not fully capture students' creative behavior in naturalistic settings.⁸ Future research should employ longitudinal designs with follow-up assessments, include process-oriented measures of creativity, and examine the model's effectiveness across diverse cultural and educational contexts.^{26,27}

5. Conclusion

This study demonstrates that the CultuSTEM pedagogical model, which integrates local culinary heritage with STEM education through a structured four-phase instructional cycle, significantly enhances creative thinking skills, STEM achievement, and cultural appreciation among Grade 10 students. The large effect sizes observed across all outcome variables, particularly the strong effects on originality ($g = 1.31$) and fluency ($g = 1.08$), indicate that culturally grounded STEM instruction can substantially foster creative thinking while simultaneously improving academic performance. The findings support the theoretical proposition that culturally responsive pedagogy and creativity education are synergistic rather than competing pedagogical goals. The CultuSTEM model offers a practical, evidence-based framework for educators seeking to develop students' creative capacities within culturally meaningful STEM contexts. Future research should explore the model's transferability across diverse cultural settings, investigate long-term effects

on creative development, and examine the mediating mechanisms through which cultural integration enhances creative thinking in STEM education.

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