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Fostering Creativity and Problem-Solving Skills in High School Science Students through Makerspaces

Aduo Frank [1], Dominic Owusu [2], Frank Blessed Amenyeke [3], Ebenezer Wirekoh Brobbey [4]

[1,2,3,4] University of Education, Winneba

Abstract

The development of creativity and problem-solving skills is critical for success in 21st-century science education. This study investigated the impact of makerspace-based learning on high school students' creativity and problem-solving abilities in science. Employing a convergent parallel mixed-methods design, the study involved 60 Form Two students from selected high schools with access to makerspace resources. Quantitative data were collected using standardized creativity and problem-solving assessments, while qualitative data were obtained through semi-structured interviews, focus group discussions, and classroom observations. Descriptive statistics and paired-sample t-tests revealed significant improvements in students' creativity (Mean difference = 13.45, $t(59) = 15.87$, $p < 0.001$, Cohen's $d = 2.05$) and problem-solving skills (Mean difference = 13.35, $t(59) = 14.92$, $p < 0.001$, Cohen's $d = 1.93$). Pearson correlation analyses indicated strong positive relationships between creativity and problem-solving at both pre-test ($r = 0.72$) and post-test ($r = 0.81$), highlighting the interdependence of these skills. Qualitative findings further illustrated that makerspace engagement fosters hands-on experimentation, iterative problem-solving, and collaborative learning, enabling students to generate innovative ideas and apply scientific reasoning effectively. The study underscores the role of makerspaces as a practical and theoretical framework for enhancing cognitive, creative, and social competencies in science education. Recommendations include the integration of makerspace activities into the curriculum, teacher training, provision of resources, and further research on long-term and technology-enhanced makerspace interventions.

Keywords: Makerspaces, Creativity, Problem-Solving Skills, High School Science, Mixed-Methods

1. Introduction

In the rapidly evolving 21st-century landscape, the ability to think creatively and solve complex problems has become a cornerstone of success across all disciplines, particularly in science, technology, engineering, and mathematics (STEM) education. High school students, positioned at a critical stage of cognitive and social development, require learning environments that not only impart foundational scientific knowledge but also nurture higher-order thinking skills such as creativity, innovation, and analytical reasoning. Traditional science classrooms, however, often emphasize rote memorization, standardized experimentation, and formulaic problem-solving approaches, which can limit opportunities for students to engage in authentic, self-directed inquiry (Bequette & Bequette, 2012; Resnick, 2017). As a result, many students struggle to apply scientific concepts to novel situations, reducing both their academic performance and their capacity to innovate.

Makerspaces—collaborative, hands-on learning environments equipped with tools, technologies, and resources for designing, prototyping, and experimenting—have emerged as promising platforms for transforming science education. These spaces encourage students to explore ideas, test hypotheses, and iteratively solve problems, integrating both creativity and critical thinking in the learning process (Martinez & Stager, 2013; Peppler & Bender, 2013). By allowing students to work on real-world projects and interdisciplinary challenges, makerspaces bridge the gap between theoretical knowledge and practical application, fostering a deeper understanding of scientific principles. Despite growing interest in makerspaces, their implementation in high school science curricula remains limited, particularly in contexts where resource constraints and traditional pedagogical practices prevail (Halverson & Sheridan, 2014).

The limited integration of makerspaces in high school science classrooms raises critical questions about how students develop creativity and problem-solving skills. While some studies suggest that hands-on, project-based learning can enhance student engagement and learning outcomes (Vossoughi, Hooper, & Escudé, 2016), there is insufficient empirical evidence detailing the specific mechanisms through which makerspaces influence scientific creativity and problem-solving. Furthermore, educators often lack clear frameworks or guidance for effectively incorporating these innovative learning environments into existing curricula. Without such understanding, students may miss out on valuable opportunities to cultivate essential 21st-century skills, potentially affecting their readiness for higher education and careers in STEM fields.

Therefore, this study seeks to investigate the role of makerspaces in fostering creativity and problem-solving skills among high school science students, addressing a critical gap in both research and practice. By exploring how engagement with hands-on, collaborative, and technologically enriched learning environments impacts students' cognitive and creative development, the study aims to provide evidence-based insights that can inform curriculum design, instructional strategies, and educational policy, ultimately contributing to more dynamic, effective, and future-ready science education.

Purpose of the Study

The purpose of this study is to investigate how makerspace-based learning experiences influence high school science students' creativity and problem-solving skills. Using a mixed-methods approach, the study examines both the measurable changes in students' performance after participating in makerspace activities and their perceptions of how these experiences support their creative thinking and scientific problem-solving.

Significance of the Study

This study is significant because it provides empirical evidence on the value of integrating makerspaces into science education at the high school level. As schools seek ways to promote 21st-century skills such as innovation, critical thinking, and real-world problem-solving, the findings will offer practical guidance on how makerspaces can enhance teaching and learning. The study also contributes to the limited research within developing contexts, offering insights that can inform curriculum design, teacher practices, resource allocation, and policy decisions aimed at improving science education outcomes.

Research Objectives

1. To determine the influence of makerspace activities on the creativity of high school science students.
2. To examine the effect of makerspace engagement on the problem-solving skills of high school science students.

Research Questions

1. How does participation in makerspace activities influence the creativity of high school science students?
2. What effect does engagement in makerspaces have on the problem-solving skills of high school science students?

LITERATURE REVIEW

Conceptualizing Creativity within Science Education

Creativity in the context of science learning is increasingly recognized as a multifaceted construct that involves the ability of learners to generate original ideas, think divergently, and apply knowledge in flexible ways to scientific problems. Rather than being viewed as a talent reserved for a select few, contemporary perspectives conceptualize creativity as a skill that can be nurtured, shaped, and demonstrated by all students when provided with supportive learning environments (Beghetto & Kaufman, 2014). In science education, creativity goes beyond artistic expression; it encompasses activities such as hypothesizing, designing investigations, constructing models, and interpreting data in innovative ways. Researchers argue that the scientific process itself is inherently creative, as it requires curiosity, exploration, and the ability to see novel connections between concepts (Kind & Kind, 2007).

Moreover, educational theorists highlight that creativity involves both **novelty** and **usefulness**, meaning that students' ideas must not only be original but also scientifically meaningful (Runco & Jaeger, 2012). Science classrooms that emphasize inquiry, experimentation, and open-ended tasks create opportunities for learners to exercise creative reasoning. As a result, creativity has become a central element of 21st-century science education frameworks, which stress that students must be equipped to innovate and adapt in rapidly evolving scientific and technological landscapes (National Research Council, 2012).

Importance of Creativity for Contemporary Science Learning

Creativity plays a critical role in modern science learning because it equips students with the ability to question assumptions, design thoughtful investigations, and propose alternative solutions to scientific challenges. In the age of advanced technology, climate change, and STEM-focused industries, creative thinking is increasingly regarded as essential for developing future scientists, engineers, and problem-solvers (Sawyer, 2012). Through creative engagement, students are more likely to develop deeper conceptual understanding, as they actively construct and reconstruct scientific knowledge rather than merely memorizing facts.

Creativity also contributes to improved motivation and engagement in science subjects. Studies show that when students are given opportunities to explore ideas freely and engage in hands-on experimentation, they become more invested in the learning process and demonstrate greater persistence in solving scientific problems (Gajda, Karwowski & Beghetto, 2017). This aligns with constructivist principles, which emphasize that meaningful learning occurs when learners take ownership of their ideas and link new knowledge to prior experiences (Vygotsky, 1978).

Furthermore, creativity enhances students' readiness for real-world scientific tasks. Complex global problems—such as environmental degradation, energy sustainability, and public health—require innovative thinking and interdisciplinary collaboration. By cultivating creativity from high school onward, science education helps learners develop the capacity to make informed decisions, propose new solutions, and participate effectively in STEM careers (Organisation for Economic Co-operation and Development [OECD], 2018).

Theoretical Perspectives Supporting Creativity in Science Education

Several learning theories offer strong support for integrating creativity into the science classroom. **Constructivist theory**, grounded in the works of Piaget and Vygotsky, posits that learners build knowledge through active engagement, exploration, and reflection. Creative tasks—such as designing experiments or constructing scientific models—align well with these principles, as they require students to manipulate materials, test ideas, and refine their thinking (Piaget, 1970; Vygotsky, 1978).

Experiential learning theory, proposed by Kolb (1984), also underscores the value of creativity. According to this theory, students learn best through cycles of concrete experience, reflective observation, abstract conceptualization, and active experimentation. Makerspace activities, which provide hands-on opportunities for iterative design and problem-solving, fit seamlessly within this framework.

From a socio-cultural perspective, creativity is seen as a collaborative process shaped by interactions between learners, peers, teachers, and tools in the learning environment (Sawyer, 2012). This view supports the idea that classrooms should encourage dialogue, shared exploration, and co-construction of scientific ideas. Similarly, **problem-based learning** and **inquiry-based learning** models emphasize student-driven investigation and creative reasoning as essential elements of scientific inquiry (Hmelo-Silver, 2004).

Together, these theories affirm that creativity is not an add-on to science learning but a fundamental component of effective instruction. They emphasize the role of environment, social interaction, and hands-on experiences in fostering students' ability to generate and refine creative scientific ideas.

Empirical Evidence on Creativity Development in Science Students

Research over the last decade has provided robust evidence that creativity can be intentionally developed through well-structured science instructional strategies. Numerous studies show that inquiry-based laboratory work, open-ended investigations, and design-based learning significantly enhance students' creative reasoning and originality in scientific tasks (Barak & Dagan, 2012). When students participate in learning environments that encourage experimentation and risk-taking, they become more confident in proposing unconventional scientific ideas.

Studies also indicate that exposing students to real-world scientific challenges stimulates curiosity and creative thinking. For example, project-based STEM activities have been shown to improve students' ability to generate multiple solutions to scientific problems and communicate scientific ideas effectively (Bell, 2010). Researchers further note that creativity is strengthened when students engage in iterative design cycles where they build prototypes, test them, and adjust their designs based on feedback (Bers, 2018).

Importantly, empirical studies emphasize the role of teacher support. Teachers who encourage open questioning, tolerate errors, and promote collaborative exploration create classroom climates that nurture creativity (Anderson & Lupart, 2018). Conversely, rigid instructional environments that prioritize rote memorization suppress creative expression in science learning.

Overall, the research consensus is clear: creativity flourishes when students engage in hands-on, exploratory, and student-centered science activities supported by flexible instructional practices.

Theoretical Framework

The theoretical foundation of this study is grounded in Constructivist Learning Theory (Piaget, 1970; Vygotsky, 1978), Experiential Learning Theory (Kolb, 1984), and Sociocultural Theory (Vygotsky, 1978). These frameworks collectively explain how high school students' engagement in makerspaces can enhance creativity and problem-solving skills within science education. The study posits that participation in makerspaces—collaborative, hands-on, and technology-rich learning environments—provides opportunities for students to actively construct knowledge, test ideas, and solve complex problems in authentic contexts, thereby developing higher-order cognitive skills essential for the 21st century.

Constructivist Learning Theory emphasizes that learners actively construct knowledge by integrating new information with prior experiences, rather than passively receiving information (Piaget, 1970). Vygotsky's extension of constructivism highlights the role of social interaction and scaffolding in cognitive development, suggesting that learning occurs most effectively when students engage with peers and more knowledgeable others within their Zone of Proximal Development (ZPD) (Vygotsky, 1978). Within the context of science education, constructivism underscores the importance of active experimentation, inquiry-based learning, and reflective thinking as mechanisms for fostering creativity. Makerspaces operationalize these principles by providing students with opportunities to explore scientific concepts, manipulate materials, and generate original solutions to problems. Through open-ended projects and iterative design processes, students develop the capacity to think divergently and creatively, as well as to apply scientific knowledge in novel ways (Kind, 2007; Peppler & Bender, 2013).

Experiential Learning Theory (ELT) further supports the integration of makerspaces in science education by emphasizing learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). ELT posits that knowledge is constructed through direct engagement with tasks and subsequent reflection on outcomes. In makerspaces, students are actively involved in building, prototyping, and testing scientific models or experiments, which provides concrete experiences that serve as the basis for critical reflection and concept formation. Iterative cycles of testing and refinement inherent in makerspace activities align with Kolb's model, fostering both creativity—through idea generation and innovation—and problem-solving skills—through evaluating, adjusting, and optimizing solutions (Martinez & Stager, 2013; Halverson & Sheridan, 2014). By emphasizing learning through doing, ELT positions makerspaces as powerful tools for bridging theoretical scientific knowledge with practical, applied problem-solving.

Sociocultural Theory complements constructivist and experiential perspectives by highlighting the central role of social interaction, collaboration, and culturally mediated tools in learning (Vygotsky, 1978). Creativity and problem-solving are not solely individual cognitive processes but are often socially situated, emerging through dialogue, peer collaboration, and guided mentorship. In makerspaces, students frequently work in teams to design, build, and troubleshoot projects, allowing them to co-construct knowledge, share diverse perspectives, and refine ideas through peer critique. Additionally, teachers and facilitators serve as scaffolds, guiding students toward more sophisticated levels of reasoning while allowing autonomy in exploration. Digital and physical tools within makerspaces, such as 3D printers, microcontrollers, and coding platforms, act as mediational means that extend students' problem-solving capabilities and support the externalization of creative thought (Peppler & Bender, 2013; Vossoughi, Hooper, & Escudé, 2016).

Integrating these theoretical perspectives provides a holistic framework for understanding the mechanisms through which makerspaces can influence high school students' creativity and problem-solving abilities. Constructivism explains the active construction of knowledge and ideation processes, Experiential Learning Theory highlights the role of hands-on iterative experimentation in developing creative solutions, and Sociocultural Theory situates learning within collaborative and socially mediated contexts that enhance cognitive growth. Together, these theories justify the study's proposition that engagement in makerspaces can lead to measurable improvements in creativity and problem-solving performance while also enriching students' experiences and perceptions of science learning. The framework thus positions makerspaces as not merely a pedagogical innovation but as a theoretically grounded, evidence-informed approach to fostering essential 21st-century skills in science education (Kind, 2007; Martinez & Stager, 2013; Halverson & Sheridan, 2014; Vossoughi et al., 2016).

Conceptual Framework

The conceptual framework illustrates the hypothesized relationships between students' engagement in makerspaces and the development of creativity and problem-solving skills in science. It is grounded in constructivist learning theory, experiential learning theory, and sociocultural theory. The framework posits that active engagement in makerspace activities provides hands-on experiences, collaborative opportunities, and reflective learning moments, which collectively enhance students' ability to think creatively and solve scientific problems.

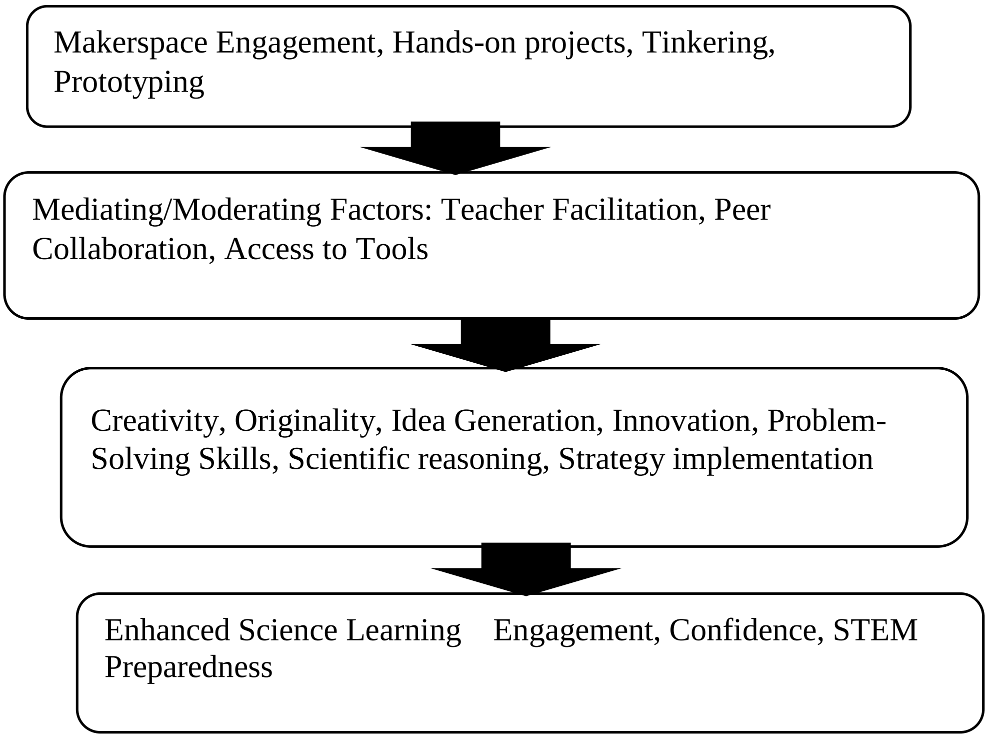

Figure 1:Conceptual Framework for Fostering Creativity and Problem-Solving Skills through Makerspaces in High School Science

The conceptual framework illustrates how engagement in makerspaces influences the development of creativity and problem-solving skills among high school science students. Makerspaces, which involve hands-on projects, prototyping, and collaborative tasks, provide authentic learning experiences that align with Constructivist Learning Theory (Piaget, 1970; Vygotsky, 1978), enabling students to actively construct knowledge through exploration and reflection. Creativity emerges as students generate original, meaningful ideas, while problem-solving skills develop as they apply these ideas to identify, evaluate, and implement solutions. The process is enhanced by mediating factors such as teacher scaffolding, peer collaboration, and access to digital and physical tools, consistent with Sociocultural Theory (Vygotsky, 1978).

The framework also reflects a cyclical, iterative process: engagement in creative problem-solving reinforces understanding, promotes further ideation, and strengthens scientific reasoning. This model positions makerspaces as a theoretically grounded, evidence-based approach for fostering higher-order thinking, creativity, and problem-solving competence in science education (Kind, 2007; Martinez & Stager, 2013; Halverson & Sheridan, 2014; Vossoughi et al., 2016).

Methodology

Research Paradigm

This study adopts a **pragmatic research paradigm**, which emphasizes the use of both quantitative and qualitative approaches to address complex educational phenomena (Creswell & Creswell, 2018). Pragmatism allows researchers to focus on the research problem and select methods that best provide meaningful insights, rather than adhering strictly to a single philosophical orientation. In this study, pragmatism supports the integration of numerical data on students' creativity and problem-solving skills with rich qualitative insights from interviews and observations, thereby providing a holistic understanding of the influence of makerspaces on science learning.

Research Design

A convergent parallel mixed-methods design was employed, in which quantitative and qualitative data were collected concurrently, analyzed separately, and then integrated to form comprehensive conclusions (Creswell & Plano Clark, 2018). This design enables triangulation, enhancing the validity of the findings, and allows the study to capture both measurable outcomes, such as changes in creativity scores, and deeper insights into students' experiences within makerspaces. The design is particularly suitable for examining educational interventions where both performance metrics and contextual understanding are critical.

Study Setting

The study was conducted in selected senior high schools that have established science laboratories and makerspace resources. These environments provide the necessary infrastructure for hands-on science activities and support student engagement in experimental and design-based learning. The choice of setting ensures that the findings are contextually relevant and applicable to schools implementing similar STEM-focused innovations.

Population, Sample, and Sampling Techniques

The target population comprised high school science students enrolled in Form Two classes. A stratified random sampling technique was used to select participants for the quantitative component, ensuring representation across gender, class level, and academic performance. For the qualitative component, purposive sampling was employed to select students, teachers, and facilitators who had direct experience with makerspace activities, allowing for rich, in-depth data on engagement, creativity, and problem-solving processes. The sample size was determined to achieve statistical power for quantitative analyses while ensuring qualitative saturation for thematic exploration.

Research Instruments

Data were collected using a combination of quantitative and qualitative instruments. *Quantitative instruments* included a standardized creativity assessment (Torrance Tests of Creative Thinking adapted for science) and a problem-solving skills test aligned with the science curriculum. *Qualitative instruments* included semi-structured interviews with students and teachers, focus group discussions, and observation checklists to capture interaction patterns, engagement levels, and creative problem-solving processes. All instruments were reviewed by experts in science education to ensure content validity.

Pilot Testing and Instrument Validation

Prior to full-scale data collection, a **pilot study** was conducted with a small cohort of students to evaluate the reliability and validity of the instruments. Cronbach's alpha was calculated for the quantitative measures to ensure internal consistency, while qualitative protocols were refined based on feedback from participants and expert reviewers. Adjustments were made to improve clarity, appropriateness, and alignment with the research objectives.

Data Collection Procedures

Data collection occurred over a six-week period during scheduled science lessons. Quantitative assessments were administered at the beginning and end of the intervention to measure changes in creativity and problem-solving skills. Simultaneously, qualitative data were collected through *observations of makerspace activities*, interviews, and focus groups to document students' experiences, strategies, and reflections. Ethical considerations were strictly adhered to, including obtaining informed consent from participants and guardians, maintaining confidentiality, and allowing voluntary participation.

Data Analysis

Quantitative data were analyzed using descriptive statistics (means, standard deviations) to summarize performance outcomes, and inferential statistics (paired t-tests, ANOVA) to examine differences pre- and post-intervention. Qualitative data were analyzed thematically, involving coding, categorization, and identification of emerging patterns related to creativity, problem-solving, and engagement (Braun & Clarke, 2006). Finally, the quantitative and qualitative findings were integrated to provide a comprehensive understanding of the impact of makerspaces on students' cognitive and creative development.

Trustworthiness and Rigor

To ensure reliability and validity, quantitative instruments were tested for internal consistency and construct validity. For qualitative data, strategies such as member checking, peer debriefing, and thick description were employed to ensure credibility, dependability, confirmability, and transferability (Lincoln & Guba, 1985). The convergence of multiple data sources strengthened the robustness of the findings and reduced potential biases.

Ethical Considerations

Ethical approval was obtained from the relevant institutional review board. Participants provided informed consent, and all data were anonymized to protect privacy. The study also respected students' rights to withdraw at any stage without penalty.

Results and Discussion

Quantitative Results

The quantitative data were analyzed to examine the effects of makerspace engagement on students' creativity and problem-solving skills. Descriptive statistics, paired-sample t-tests, and correlation analyses were conducted to assess changes between pre-test and post-test scores and to explore the relationship between creativity and problem-solving. The results are summarized in Tables 1, 2, and 3.

Table 1: Descriptive Statistics of Pre-Test and Post-Test Scores

Variable	N	Pre-Test Mean	(SD)	Post-Test Mean	(SD)	Difference
Creativity Score	60	45.30	(6.25)	58.75	(5.80)	13.45
Problem-Solving Score	60	42.85	(5.90)	56.20	(6.10)	13.35

Note: SD = Standard Deviation

The descriptive statistics in Table 1 show that students' *Creativity* scores increased from a pre-test mean of 45.30 (SD = 6.25) to a post-test mean of 58.75 (SD = 5.80), while *Problem-Solving* scores improved from 42.85 (SD = 5.90) to 56.20 (SD = 6.10). This indicates substantial improvement in both variables following engagement in makerspace activities. The mean differences of 13.45 and 13.35 suggest that the intervention had a notable positive effect on students' creative thinking and problem-solving skills.

Table 2: Paired Sample t-test Results for Pre-Test and Post-Test Scores

Variable	Mean Difference	T	Df	p-value	Cohen's d
Creativity Score	*13.45*	*15.87*	*59*	<0.001	2.05
Problem-Solving Score	*13.45*	*14.92*	*59*	<0.001	1.93

Note: Cohen's d interpreted as large effect size (Cohen, 1988)

Table 2 presents the results of paired-sample t-tests comparing pre-test and post-test scores. The analysis shows statistically significant increases in both *Creativity* ($t(59) = 15.87$, $p < 0.001$, Cohen's $d = 2.05$) and *Problem-Solving* ($t(59) = 14.92$, $p < 0.001$, Cohen's $d = 1.93$) scores. The large effect sizes, as interpreted using Cohen's (1988) criteria, indicate that the makerspace intervention had a strong and meaningful impact on students' cognitive and creative abilities.

Table 3**:** Pearson Correlation Between Creativity and Problem-Solving Scores

Variable	**Pre-Test r**	**Post-Test r**
Creativity & Problem-Solving	0.72**	0.81**

*p < 0.01

As shown in Table 3, there is a strong, positive correlation between *Creativity* and *Problem-Solving* scores at both pre-test ($r = 0.72$, $p < 0.01$) and post-test ($r = 0.81$, $p < 0.01$). This suggests that students who performed well in creative tasks also tended to demonstrate stronger problem-solving abilities, and that this relationship was strengthened following the makerspace intervention

Qualitative Results

The qualitative data were analyzed thematically to explore students' and teachers' experiences with makerspace activities and how these experiences influenced creativity and problem-solving skills. Three major themes emerged from the data: *enhanced creativity, improved problem-solving strategies, and collaborative learning experiences*.

Theme 1: Enhanced Creativity

Participants frequently reported that makerspace activities provided opportunities to *think outside the box and generate original ideas*. Students described how designing experiments, building models, and prototyping encouraged them to experiment with multiple solutions. One student noted:

"I enjoyed trying different ways to build the circuit. I had to come up with my own design, which made me more creative than before."

Teachers also observed increased innovation in students' projects:

"Students who were usually quiet in class became very active when they could create something hands-on. Their ideas were more imaginative and varied."

Theme 2: Improved Problem-Solving Strategies

Engagement in makerspaces promoted the development of *strategic thinking and iterative problem-solving*. Students described how encountering challenges required them to evaluate options, troubleshoot errors, and refine their approaches. One student explained:

"When my design didn't work the first time, I had to figure out what was wrong and try again. This taught me how to solve problems step by step."

Teachers highlighted those students were increasingly able to apply *scientific reasoning and logic* in hands-on tasks:

"I noticed students thinking critically about their experiments, testing different variables, and learning from mistakes rather than giving up."

Theme 3: Collaborative Learning Experiences

Collaboration emerged as a key factor in enhancing both creativity and problem-solving. Working in groups allowed students to *share ideas, critique each other's designs, and co-construct solutions*. One participant noted:

"Working with my friends helped me see different ways of solving the same problem. We combined our ideas and created something better together."

Teachers also reported that peer interaction fostered a supportive learning environment:

"Students learned not only from their own experiments but also from observing and discussing their peers' approaches. This strengthened teamwork and idea generation."

Summary of Qualitative Findings

Overall, the qualitative data suggest that makerspace engagement *enhances students' creativity, develops systematic problem-solving skills, and promotes collaborative learning*. These findings corroborate the quantitative results, demonstrating that hands-on, interactive, and socially mediated learning environments can significantly enrich science education outcomes.

Integrated Summary of Quantitative and Qualitative Findings

The findings of this study demonstrate that engagement in makerspace activities positively influenced high school students' *creativity* and *problem-solving skills*.

Quantitative results revealed significant improvements in both constructs. Descriptive statistics indicated an increase in mean creativity scores from 45.30 ($SD = 6.25$) to 58.75 ($SD = 5.80$) and problem-solving scores from 42.85 ($SD = 5.90$) to 56.20 ($SD = 6.10$) following the intervention (Table 1). Paired-sample t-tests confirmed that these gains were statistically significant (Creativity: $t(59) = 15.87$, $p < 0.001$, Cohen's $d = 2.05$; Problem-Solving: $t(59) = 14.92$, $p < 0.001$, Cohen's $d = 1.93$) (Table 2), indicating a strong effect of makerspace engagement. Additionally, Pearson correlation analyses revealed a positive relationship between creativity and problem-solving scores at both pre-test ($r = 0.72$, $p < 0.01$) and post-test ($r = 0.81$, $p < 0.01$) (Table 3), suggesting that students who demonstrated higher creativity also tended to exhibit stronger problem-solving abilities.

Qualitative findings corroborated and enriched these results. Thematic analysis identified three major themes: *enhanced creativity, improved problem-solving strategies, and collaborative learning experiences***.** Students reported that makerspace activities provided opportunities to experiment, generate novel ideas, and troubleshoot challenges iteratively. Teachers noted that students became more innovative, strategically thoughtful, and actively engaged in collaborative problem-solving tasks. Participants emphasized that peer collaboration and teacher scaffolding supported creative ideation and effective solution development.

Integration of Findings: Both quantitative and qualitative results converge to suggest that makerspaces serve as effective pedagogical tools for developing 21st-century skills in science education. The quantitative data provide empirical evidence of measurable improvements in creativity and problem-solving, while the qualitative data explain *how and why these improvements occur***,** highlighting the role of hands-on experimentation, reflective practice, and collaborative interaction. Together, these findings demonstrate that a mixed-methods approach offers a more nuanced understanding of the impact of makerspaces than either method alone.

Discussion

The findings of this study indicate that engagement in makerspace activities significantly enhances high school students' *creativity* and *problem-solving skills*, supporting the efficacy of hands-on, collaborative, and experiential learning environments in science education. The quantitative results revealed substantial increases in students' creativity scores (Mean difference = 13.45, $t(59) = 15.87$, $p < 0.001$, Cohen's $d = 2.05$) and problem-solving scores (Mean difference = 13.35, $t(59) = 14.92$, $p < 0.001$, Cohen's $d = 1.93$), demonstrating both statistical and educational significance. The positive correlations between creativity and problem-solving scores at pre-test ($r = 0.72$, $p < 0.01$) and post-test ($r = 0.81$, $p < 0.01$) suggest that these skills are closely intertwined, with improvements in one domain likely supporting development in the other. These findings are consistent with prior studies indicating that *interactive, design-based learning experiences* foster higher-order cognitive skills in STEM education (Martinez & Stager, 2013; Halverson & Sheridan, 2014).

The qualitative findings provide a deeper understanding of *how and why* makerspaces influence these outcomes. Three major themes emerged: **e***nhanced creativity, improved problem-solving strategies, and collaborative learning experiences*. Students reported that the open-ended, hands-on nature of makerspaces encouraged experimentation, iteration, and ideation, which aligns with *Constructivist Learning Theory*, emphasizing that knowledge is actively constructed through experience and reflection (Piaget, 1970; Vygotsky, 1978). For example, students described generating multiple design solutions and learning from trial and error, demonstrating *divergent thinking* and creative flexibility. Teachers corroborated these observations, noting that even previously disengaged students became more active and innovative when provided with a supportive, resource-rich environment.

The development of *problem-solving skills* observed in both quantitative and qualitative data can be interpreted through the lens of *Kolb's Experiential Learning Theory* (1984), which posits that learning occurs through cycles of concrete experience, reflection, conceptualization, and active experimentation. Students' iterative engagement with challenges—such as troubleshooting circuits, prototyping models, and testing hypotheses—enabled them to apply scientific reasoning systematically, evaluate multiple solutions, and refine strategies, thereby enhancing their problem-solving competence.

Collaboration emerged as a critical mediating factor, supporting both creativity and problem-solving. Working in teams allowed students to *share perspectives, critique ideas, and co-construct solutions, illustrating Vygotsky's Sociocultural Theory*, which highlights the importance of social interaction and cultural tools in cognitive development (Vygotsky, 1978). Peer feedback and cooperative problem-solving facilitated reflective thinking and idea improvement, which complemented individual experimentation and reinforced learning outcomes. This finding aligns with prior research suggesting that collaborative makerspace activities not only enhance cognitive skills but also foster social and communication competencies (Peppler & Bender, 2013; Vossoughi, Hooper, & Escudé, 2016).

Practical implications of these findings are substantial. Incorporating makerspace-based, hands-on learning in high school science curricula can provide meaningful opportunities for students to engage in *creative inquiry, critical thinking, and applied problem-solving.* Teachers play a vital role in scaffolding learning, providing guidance, and facilitating peer collaboration. Access to appropriate tools and resources further strengthens the efficacy of makerspaces as pedagogical interventions. These insights suggest that educational policymakers and curriculum developers should prioritize the integration of makerspaces and similar experiential learning environments to foster essential 21st-century skills

Delimitations and Limitations

This study was delimited to high school science students in selected schools with access to makerspace resources, focusing specifically on the development of creativity and problem-solving skills in science education. The choice of schools, sample size, and specific constructs measured (creativity and problem-solving) were intentional to provide a focused and manageable scope for in-depth mixed-methods analysis. However, certain limitations should be acknowledged. The sample was relatively small and drawn from a limited geographic area, which may affect the generalizability of the findings. Additionally, some qualitative data relied on self-reported experiences, which could introduce response bias, and the study's short intervention period may limit understanding of long-term effects. Despite these constraints, the study provides valuable insights into the potential of makerspaces to enhance 21st-century skills in science education and offers a foundation for future research in broader contexts.

Conclusion and Recommendations

Conclusion

The study demonstrates that engagement in makerspace activities significantly enhances high school students' creativity and problem-solving skills in science education. Both quantitative and qualitative findings indicate that hands-on, collaborative, and reflective learning experiences provide students with opportunities to generate innovative ideas, apply systematic problem-solving strategies, and engage in meaningful peer interaction. The integration of these experiences fosters cognitive, social, and creative competencies that are essential for success in STEM disciplines. The findings are consistent with Constructivist, Experiential Learning, and Sociocultural theoretical perspectives, highlighting the value of active, student-centered learning environments in promoting 21st-century skills.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. High schools should incorporate makerspace-based learning activities into the science curriculum to provide students with regular opportunities for hands-on, creative, and problem-solving experiences.
2. Science teachers should receive professional development to effectively facilitate makerspace activities, provide scaffolding to support creativity and problem-solving, and encourage reflective learning practices.
3. Schools should ensure that students have consistent access to appropriate tools, materials, and collaborative spaces necessary for effective makerspace engagement.
4. School administrators and policymakers should prioritize the establishment, maintenance, and continual improvement of makerspaces, including allocating funding and infrastructure support.
5. Policymakers and school leadership should provide curricular guidance and professional development programs to enhance the impact of makerspace interventions on student learning outcomes.
6. Future studies should explore the long-term effects of makerspace engagement, examine its impact across diverse student populations, and investigate the potential of technology-enhanced makerspaces to further strengthen creativity and problem-solving skills in science education.

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