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Integrated STEAM and Problem-Based Learning: A Teaching Framework to Enhance Undergraduates' Creative Thinking

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Abstract

With the growing importance of creative thinking in the modern world, there is a need for innovative teaching methods that can effectively cultivate this skill in undergraduates. This study introduces an integrated framework combining STEAM (Science, Technology, Engineering, Arts, and Mathematics) education with Problem-Based Learning (PBL) to enhance undergraduates' creative thinking through linear algebra courses. This framework was implemented during an 8-week course at a private university in Chongqing. This course incorporated real-world challenges, engaging students in interdisciplinary tasks, including mathematical modeling, computational analysis, and artistic representations. Instructors guided students through creative exploration and reflective practice to foster the core aspects of creative thinking: fluency, flexibility, originality, and elaboration. Qualitative observations and students feedback revealed that the STEAM-PBL framework significantly improved engagement and promoted the application of interdisciplinary knowledge. The findings present a replicable framework for creative teaching in higher education, highlighting its potential to foster creative thinking (CT) through the integration of interdisciplinary approaches and problem-based learning.

Keywords: STEAM, PBL, Creative Thinking, Linear Algebra, TTCT

Introduction

In the digital age, the importance of creative thinking has been consistently emphasized, encompassing collaboration with AI, transcending traditional boundaries, and converting imaginative concepts into feasible solutions. Creative thinking is an essential skills that enables individuals to generate innovative ideas and devise solutions to problems(Emma Suganda, 2021). In the 21st-century, it is imperative that students receive an education focused on practical skills to address real-world challenges. Thus, determining an effective educational method or approach is essential (Emma Suganda, 2021). There has been a significant increase in the adoption of STEAM (Science, Technology, Engineering, Arts, and Mathematics) and PBL (Problem-based Learning) within education frameworks. Various nations have initiated strategic projects and initiatives designed to enhance interdisciplinary leaning through STEAM education (Kuo, 2024). Mathematics education serves to cultivate essential skills such as creative thinking, critical thinking, problem solving, communication, innovation, and collaboration. These competencies are crucial for students to meet the demands of the 21st century. Teachers should prioritize designing learning experiences that stimulate students' potential to use their creative thinking skills for solve problems (Coelho & Cabrita, 2015).

As technological advancements continue, the STEAM approach has become increasingly prevalent across diverse educational settings. It is effectively utilized to cultivate creative thinking skills (Anindya, 2020; Wandari, Fany, Wijaya, & Agustin, 2018). The STEAM approach can be effectively integrated with environmental concepts, and PBL model has been shown to enhance students' creative thinking and motivation (Avsec & Šinigoj, 2016; dos Santos, da Silva Figueira-Sampaio, & Carrijo, 2015). PBL is a pedagogical model where students engage with real-world problems, enabling them to build their own knowledge base while cultivating high order thinking and inquiry skills. This approach also fosters independence and confidence (Arends, 2014).

Aligned with current global educational trends, this study develops an interdisciplinary course integrating STEAM with PBL. This study explores the impact of this integration on students' CT. The application of STEAM integrated with PBL is relatively novel in China's higher education, particularly in mathematics education. The STEAM-PBL model is an alternative educational approach that enhances creative thinking skills. It allows students the space to explore and collaboratively construct their own concepts within groups settings (Y Selvy, 2020). The STEAM-PBL comprises four phases: 1) orientating students to the problem, 2) guiding individual and group investigations, 3) developing and presenting solutions, and 4) analyzing and evaluating the problem-solving process. Additionally, the STEAM-PBL model offers numerous benefits, including enhancing contextual problem-solving skills, facilitating new knowledge acquisition, and developing students' ability to think both creatively and critically. It also significantly boosts students' motivation to learn (Arends, 2014). This research specifically explores the integration of STEAM with PBL in linear algebra courses to enhance the creative-thinking skills of undergraduates' (Suganda, Latifah, Sari, Rahmayanti, Ichsan, & Rahman, 2021).

Literature Review

STEAM

As STEM gains traction in American K-12 education, scholars have introduced various models and pedagogical strategies for incorporating the arts into STEM classrooms. STEAM education which adds the Arts to the traditional STEM framework (Science, Technology, Engineering, and Mathematics), was established as a novel pedagogical approach during the 2007 Americans for the Arts-National Policy Roundtable. This approach was developed in response to the growing need to enhance student interest and competencies in STEM fields (Allina, 2013; Daugherty, 2013; Quigley, Herro, & Jamil, 2017). STEAM education represents an interdisciplinary approach that enriches traditional STEM disciplines by incorporating the arts. This integration broadens the educational framework, aiming to boost student engagement, enhance creativity and innovation, improve problem-solving capabilities, and deliver additional cognitive advantages (Hetland & Winner, 2004; Root-Bernstein, 2015). Yakman

(2008) proposed the STEAM-PBL framework, structured as a five-layer pyramid, has been proposed to guide curriculum content across STEAM disciplines. The second layer emphasizes individual learning within these subjects. The third layer focuses on interdisciplinary learning within STEM by incorporating the arts. The fourth layer of integrates these subjects within the broader context of STEAM education, promoting problem-solving through interdisciplinary methods, notably the PBL approach. The apex of the pyramid is dedicated to fostering lifelong learning and a holistic educational experience, enabling students to gain knowledge across various disciplines and engage in sophisticated communication with peers. Positioning the arts within this scientific framework marks a strategic shift that encourages innovative thinking, acknowledges cultural diversity, and highlights the integral connection between arts and technology, all essential for nurturing a well-rounded educational approach.

Problem-Based Learning (PBL)

Problem-Based Learning (PBL) is a student-centered pedagogical framework that emphasizes learning through the exploration of real-world problems. Originally developed for medical education, PBL has since been widely adopted across various disciplines, including mathematics (Barrows, 1980) This approach encourages students to take an active role in their learning by constructing knowledge collaboratively and critically evaluating solutions (Hmelo-Silver, 2004). In the context of mathematics education, PBL has shown significant potential for improving student engagement and understanding of abstract concepts. Woods, Duncan-Hewitt, Hall, Eyles and Hrymak (1996) demonstrated that PBL encourages students to actively construct mathematical knowledge, fostering a deeper understanding compared to traditional lecture-based methods. Similarly, Stewart and Thomas (2019) found that embedding mathematical problems in real-world contexts boosts students' interest and motivation. Additionally, Hung (2011) emphasized the value of open-ended PBL tasks, which allow students to explore diverse solution pathways and develop adaptable problem-solving strategies. Despite these benefits, the integration of PBL into traditional mathematics curricula is often limited. This limitation is partly due to the heavy emphasis on theoretical rigor at the expense of practical problem-solving. Innovative approaches that balance theoretical depth with application-oriented learning are essential to overcoming these challenges.

The Synergy of STEAM and PBL

The combination of STEAM and PBL creates a model that enables students to actively engage in and explore interdisciplinary knowledge. Aguilera and Ortiz-Revilla (2021) conducted meta-analyses of comprehensive studies, providing empirical evidence that the integration of STEAM/STEM with PBL can significantly enhance creativity. Combining STEAM education with PBL offers a promising framework for enhancing undergraduates' CT in mathematics education. By integrating interdisciplinary perspectives with problem-driven learning, this hybrid model enables students to connect abstract mathematical theories to practical applications (Capraro & Slough, 2013). The open-ended, exploratory nature of PBL tasks aligns seamlessly with STEAM's emphasis on interdisciplinary integration, allowing students to apply theoretical knowledge to real-world scenarios (Diego-Mantecon, Prodromou, Lavicza, Blanco, & Ortiz-Laso, 2021).

The STEAM-PBL model through practical tasks using linear algebra. These activities not only engage students but also deepen their understanding of mathematical principles by demonstrating their relevance to solving real-world problems. While the potential of combining STEAM and PBL has been widely acknowledged, empirical research on its application in higher education remains limited. This gap is particularly evident in advanced mathematics courses, such as linear algebra. Further studies are needed to evaluate the effectiveness of STEAM-PBL in enhancing student engagement and knowledge acquisition, paving the way for broader implementation in higher education.

Creative Thinking (CT)
Creative thinking is a cognitive process aimed at generating new and original ideas, often linked to the characteristics of mathematical giftedness (Krutet͡skiĭ, 1976; Y Selvy, 2020). This definition extends Guilford (1967) categorization of creativity into nine constructs: flexibility, fluency, synthesis, novelty, reorganization, analysis, complexity, and elaboration. Other scholars have proposed variations of Guilford's definition of creativity (Sternberg, 1999; Torrance, 1988). One research focus is cognitive process underlying CT (Kurtzberg & Amabile, 2001). This research explores the mental activities that occur during CT. One explanation is derived from the concept of human insight (Perkins, 2013). Researchers suggest that creative thinkers utilize lateral thinking, a process where thoughts flexibly transition between different aspects rather than adhering strictly to established pathways. Lateral thinking involves the capability to think associatively, leveraging diverse perspectives to think outside the conventional framework and generate innovative ideas. Divergent thinking represents another response to the question of what occurs mentally during creative thinking. In divergent thinking, individuals produce a variety of solutions to problems that lack definitive right or wrong answers (Volle, 2018).

Research highlights the significant impact of STEM and PBL approaches on various dimensions of creativity. Teachers play a pivotal role in fostering innovative thinking by guiding students through processes such as observation, exploration, questioning, and the idea synthesis, often supported by the web-based applications. However, findings indicate that while PBL courses positively influence the networking of ideas among Chinese students， they do not significantly enhance skills related to observation, exploration, or questioning. This suggests that different implementations of STEAM and PBL may have varying effects on specific aspects of creative and innovative thinking. Kuo (2024) utilized a quasi-experimental design to examine the effects of integrating STEAM and PBL on students' creative thinking， conducting the experimental instruction over a semester.

There is increasing evidence supporting the integration of STEAM with PBL as an effective approach to enhancing students' CT. Empirical studies have identified sever features of this integration that positively impact student learning and CT development, including long-term projects, small group activities, effective assessment practices, the seamless combination of STEAM with PBL, and ongoing professional development for teachers. However, some studies indicate that the combined application of STEAM and PBL does not consistently yield significant improvements in CT. Factors contributing to these mixed outcomes include excessive workloads, challenges associated with hybrid and blended learning models, and insufficient time for collaborative group projects. These findings underscore the importance and timeliness of the current study in addressing these challenges and advancing the understanding of how STEAM and PBL can effectively foster creative thinking.

Research Methodology

Research Design

Employing a quasi-experimental approach, sophomore students from a private university in Chongqing were divided into three groups (Table 1). The quasi-experimental design is widely regarded as a valid methodology for investigating causality in real-world settings, particularly when random assignment is impractical (Creswell, 2015). One notable advantage of this design is its external validity, as participants are taught or treated within their natural environment without disrupting their ongoing processes or surroundings. This enhances the generalizability of the study findings to similar populations or contexts. A pre-test and post-test design was implemented to evaluate the effect of the intervention. Participants were selected using a random sampling strategy. The experimental group comprised 29 sophomores from the same major, with a gender distribution of 18 males and 11 females. The control group included 59 students, with 34 males and 25 females. Both groups were instructed by the same team of teachers, ensuring consistency in teaching practices throughout the study. The pre-test and post-test results were compared between the experimental group (29 students in one class) and the control group (59 students in two classes). The intervention consisted of 8 lessons, during which the experimental group participated in the newly developed STEAM-PBL course, while the control group followed a traditional teaching approach. Students in both groups exhibited similar baseline levels of creative thinking, providing a robust foundation for comparative analysis post-intervention. The curriculum content for both groups was identical and aligned with the teaching syllabus and instructional plan established by the private university in Chongqing.

Table 1
Experimental Design

Group	Pre-test	Courses are conducted	Post-test
Experimental Group, A	O1	X	O2
Experimental Group, B	O1	Y	O2
Traditional Group	O1		O2

O: Represents the scores or measurements.
X: Represents the STEAM -PBL module.
Y: Represents the PBL module.

Research Instrument

The Torrance Tests of Creative Thinking (TTCT) Verbal Form was selected as the primary instrument for assessing CT due to its wide applicability and well-established design. The TTCT evaluates CT across four key dimensions: fluency, flexibility, originality, and elaboration. Originality was measured by the uniqueness of responses, with higher scores assigned to rare and uncommon ideas. Fluency was assessed by the total number of relevant responses generated within the allotted time. The test was administered in two sessions, each lasting 45 minutes. Clear and standardized instructions were provided beforehand to ensure that all participants fully understood the tasks. The sessions were conducted in a quiet, and controlled classroom environment to minimize distractions and maintain uniform testing conditions. The TTCT is widely recognized for its robust reliability and validity in evaluating creativity. To ensure consistency in scoring, inter-rater reliability was calculated using Cohen's kappa, with two independent raters evaluating the tests. The data collected were analyzed using descriptive statistics to summarize participant performance and independent t-tests to compare creativity scores between the experimental and control groups.

Instructional Design and Implementation Framework

Instructional Design Framework

The STEAM-PBL instructional design framework integrates interdisciplinary problem-solving with the development of creative thinking. Rooted in constructivist learning theory, this framework emphasizes student-centered learning and active engagement. Its implementation follows a structured four-step process, each step systematically designed to foster undergraduates' CT.

Step1: Problem Definition. Each learning module begins with a practical, real-world problem that aligns with the core concepts of linear algebra. For example, one task challenges students to apply matrix transformations, including rotation, scaling, and shifting, to optimize urban traffic flow. These problems are presented in an open-ended format to encourage exploration, collaboration, and creative solutions. Additionally, the process incorporates creative task design, collaborative learning, and iterative reflection to refine understanding and problem-solving strategies.

Step2: Creative task design. Tasks are systematically crafted to integrate core elements of STEAM disciplines, fostering interdisciplinary application and innovation. For instance, in the traffic optimization task, students are required to analyze the problem from a mathematical perspective, utilizing matrices and transformations. The computational model is implemented using programming tools such as Python or MATLAB. and solutions are visualized through dynamic and artistic representations. This approach not only promotes interdisciplinary learning but also facilitates the effective communication of research findings.

Step3: Collaborative learning. Students are divided into small groups of 4-5 members to encourage peer learning and collaboration. Each team identifies key challenges, brainstorms potential solutions, and assigns roles based on individual strengths and expertise. The teacher assumes the role of a facilitator, supporting discussion, providing resources, and guiding the process without imposing specific solutions. This collaborative approach nurtures teamwork, problem-solving skills, and shared responsibility.

Step4: Reflection and iteration. At the conclusion of each module, groups present their solutions to the class. Feedback is provided by both peers and mentors, emphasizing originality, practicality, and the effective interdisciplinary integration of solutions. Based on this feedback, groups iterate on their designs to refine and improve their approach. This iterative process strengthens critical thinking, adaptability, and the capacity to integrate diverse perspectives into problem-solving.

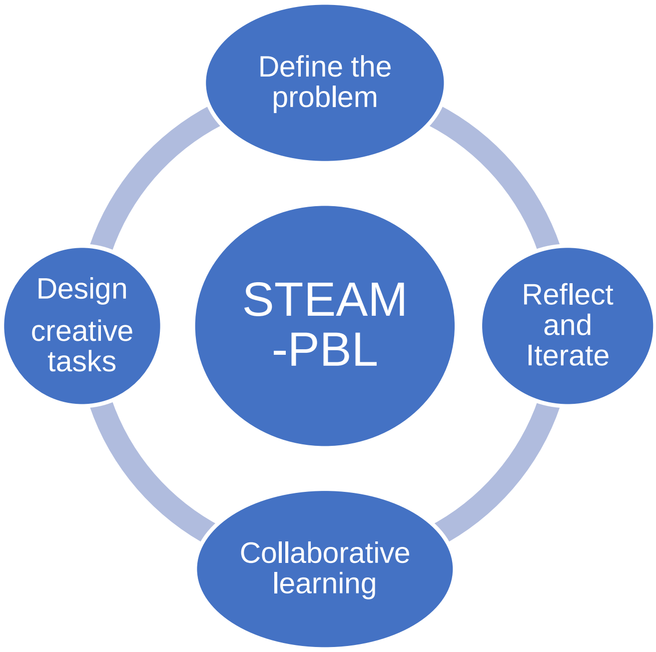

Figure 1 The approach of STEAM-PBL

Case Study: A STEAM-PBL Module

To enhance undergraduate' CT, the researcher developed a series of structured tasks aligned with the four dimensions of creativity defined by the Torrance Test of Creative Thinking (TTCT): fluency, flexibility, originality, and elaboration. Each task is specifically designed provide students within both a theoretical understanding and a practical application of matrices within an interdisciplinary context. The following table outlines the matrix concepts, corresponding objectives, and detailed scoring criteria used to evaluate students' performance.

Table 2
Experimental Design

Dimensionality	Task description	Goal	Scoring standard
Fluency	List all possible applications of the matrix in the following five areas: and briefly describe its role: 1. Image processing. 2. Data analysis. 3. Cryptography. 4. Physical simulation. 5. Social network analysis.	Students are tested on their ability to generate many relevant answers in a short period of time.	1. Score 1 point for each reasonable answer. 2. Extra points for the number of answers generated per unit time.
Flexibility	Choose two or more of the following fields (engineering, art, economics, medicine, ecology) and each design a matrix-based application that describes its principles and practical implications.	Tests students' ability to think from multiple perspectives (interdisciplinary).	1.Number of applications in different fields. 2.Diversity of each scheme (such as technical principle, application direction, scope of influence).
Originality	Please combine the matrix with one of the following disciplines to design an innovative interdisciplinary application and describe its practical effects and potential significance. Choose a discipline: 1.Art (such as 3D modeling or animation). 2.Medical (genetic data analysis). 3.Education (such as intelligent teaching tools); 4.Engineering (building optimization design).	Students are tested on their ability to generate new, unique ideas.	1. Novelty of the answer: whether it is creative. 2.The uniqueness of the application: whether it is different from common methods.
Elaboration	Design an interactive teaching tool that shows the transformation process of multiplication on two-dimensional graphs (such as rotation, scaling, translation). Please describe in detail: 1.Design of tool interface. 2.Operation mode of user interaction. 3.Teaching objectives of the tool and its realization.	Test students' refinement ability and tool realizability thinking.	1. Describe the level of detail: whether it includes interactive interface design, module function. 2.Operability: Whether the design is realizable.

Discussion

This study proposes a PBL teaching model grounded in the concept of STEAM education. STEAM education emphasizes the integration of disciplines to address practical problems from a multidisciplinary perspective, often explored through specific experiments or projects. The PBL model effectively supports this interdisciplinary approach by encouraging active learning and problem-solving. However, implementing PBL within the STEAM framework, particularly in the context of linear algebra, presents several challenges. These include effectively incorporating STEAM knowledge into linear algebra, balancing the depth of interdisciplinary knowledge in teaching design, seamlessly integrating STEAM concepts seamlessly into course content, and overcoming disciplinary boundaries. Additionally, the development of localized STEAM case studies could improve the feasibility and adaptability of its implementation. Addressing these challenges requires ongoing exploration and practice by scholars and educators in this field. The integration of STEAM and PBL approaches has several advantages. First, it effectively enhances learner engagement and task motivation (Fong, Kremer, Cox, & Lawson, 2021; Lu, Lo, & Syu, 2021; Lu, Wu, & Huang, 2022; Uğraş, 2018). Second, incorporating real-world problems into educational settings enriches learning experiences, making them more relevant and impactful (Rina Novalinda, 2020; Virtue & Hinnant-Crawford, 2019). Third, the hands-on activities central to these methods promote the practical application of acquired knowledge. Finally, the teamwork inherent in both STEAM and PBL fosters dynamic brainstorming and collaboration, which significantly enhance creative thinking (Onarheim & Friis-Olivarius, 2013).

Participants in the STEAM-PBL course collaborated on a variety of PBL tasks. The study revealed that while most students demonstrated significant improvements in learning engagement and task motivation, a small minority of less active participants faced challenges in fully engaging with group work and immersing themselves in collaborative activities. Despite these challenges, the open-ended and thought-provoking nature of the PBL questions had an overall positive impact on students' learning experiences. The STEAM-PBL approach provided the experimental group with meaningful learning opportunities, enabling them to apply interdisciplinary knowledge in realistic contexts, enhance original thinking skills, and refine existing ideas, concepts, or solutions. Group discussion and collaboration fostered a supportive and dynamic learning environment that encouraged meaningful teamwork. Reflective observation further highlighted a marked improvement in students' ability to think creatively, evaluate the perspectives of others, and strengthen their own ideas.

To ensure the effective integration of STEAM and PBL, this research project emphasized the creation of a cohesive learning community comprising teachers, professionals, and students. Notably, the Ministry of Education's advanced interdisciplinary program supports collaboration among faculty from diverse subject areas. This interdisciplinary collaboration plays a crucial role in connecting educators across disciplines, facilitating the alignment of learning content with various educational objectives. Such collaboration also promotes the inclusive translation of theoretical knowledge into practical teaching strategies, enriching the overall learning experience.

Conclusion

This study employs the TTCT to investigate the impact of innovative linear algebra instruction on undergraduates' creative thinking, addressing a notable gap in the existing literature. By integrating STEAM education and PBL into linear algebra pedagogy, the study observed significant improvements in students' creative thinking skills. These findings highlight the transformative potential of combining STEAM and PBL methodologies in fostering creativity, providing valuable insights for educational strategies aimed at developing such skills to address diverse academic and real-world challenges. The results demonstrate that the STEAM-PBL approach fosters active participation by engaging students in interdisciplinary, real-world problem-solving tasks. These tasks contextualize abstract mathematical concepts, such as matrices, in practical applications like network optimization and resource allocation, thereby making the content more accessible and relevant. Furthermore, the model promotes collaborative learning, enhancing students’ conceptual understanding while developing essential skills such as teamwork, problem-solving, and effective communication. From a practical perspective, this study offers a scalable teaching framework for higher education mathematics. It underscores the value of integrating real-world scenarios into the curriculum, equipping educators with the tools and strategies to design interdisciplinary tasks. By leveraging computational tools such as MATLAB, the framework facilitates hands-on learning experiences that enhance student engagement and deepen their understanding of mathematical concepts. These strategies prepare students to navigate future academic and professional challenges.

In conclusion, the STEAM-PBL framework represents a promising model for improving student engagement and conceptual understanding in linear algebra. By bridging theoretical knowledge with practical applications, it transforms traditional teaching methods into interactive and impactful learning experiences. These findings contribute to the ongoing efforts to innovate mathematics education and establish a foundation for future research into interdisciplinary teaching methodologies.

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