



A Study of Creativity in CaC₂ Steamship-derived STEM Project-based Learning

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ABSTRACT

This study mainly aimed to explore the effects of project-based learning (PBL) integrated into science, technology, engineering and mathematics (STEM) activities and to analyze the creativity displayed by junior high school students while performing these activities. With a quasi-experimental design, 60 ninth-grade students from a junior high school in southern Taiwan were selected as subjects to participate in the six-week teaching experiment. The teaching design was centered on STEM activities and integrated with the strategy of project-based learning. The teaching contents included teaching materials integrating CaC₂ steamship-derived knowledge of science, technology, engineering, mathematics, physics and chemistry as well as related teaching activities. Three conclusions were drawn. First, the key teaching points of the five stages of STEM project-based learning—preparation, implementation, presentation, evaluation and correction—can improve students' creativity. The learning objectives of STEM project-based learning can strengthen students' ability in STEM learning and STEM-integrated application. STEM project-based learning can further develop the affective domain of creativity, including adventurousness, curiosity, imagination and challenge. Based on the conclusions, this paper proposes suggestions regarding the implementation of STEM PBL activities to enhance the creativity and STEM-integrated application ability of junior high school students.

Keywords: CaC₂, creativity, project-based learning, steamship, STEM

INTRODUCTION

Innovation is regarded as a process where a series of knowledge is produced, utilized and spread, and creativity is the very flame of innovation (Ministry of Education, 2002). Countries worldwide share a vision to cultivate creative people in this era, with the rapid development and circulation of science, technology and information. Both Taiwan's White Paper on Science Education and the Guidelines of Grade 1-9 Curriculum of Elementary and Junior High School

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State of the literature

- Science, technology, engineering and mathematics & project-based learning (STEM-PBL) is a model of teaching and learning that is based on the connotations of STEM education and integrated with the PBL curriculum design.
- Project-based learning include research activities to make students concentrate on such complicated tasks as design, problem resolution and decision making.
- Three teaching models to help teachers implement the STEM-PBL: the central project approach, the student-led projects approach, and the use of student-led projects as the curriculum.

Contribution of this paper to the literature

- The key teaching points of the five stages of STEM-PBL: preparation, implementation, presentation, evaluation and correction, can improve students' creativity.
- The learning objectives of STEM-PBL can strengthen students' ability in STEM learning and STEM-integrated application.
- STEM-PBL can further develop the affective domain of creativity, including adventurousness, curiosity, imagination and challenge.

Education issued by the Ministry of Education list the cultivation of creativity as one important goal for reform (Chen, 2010). These examples indicate that current education no longer merely emphasizes imparting knowledge but also pays attention to students' experience in the creation and exploration of such experience.

Recent curriculum reform in the United States has been directed towards cultivating the integrated qualities and abilities related to such disciplines as science, technology, engineering and mathematics (hereinafter referred to as "STEM"). Relevant research reports note that the STEM curriculum is closely connected to America's maintenance of its future economic competitiveness and innovation skills. Since President Obama took office in 2009, he has consistently ascribed great importance to the cultivation of STEM talents and expressed the hope that students can acquire and deepen their critical thinking through STEM learning to excel in innovation skills and creativity (Obama, 2010). In 2013, President Obama released an integrated national strategy to cultivate STEM talents and introduced STEM innovation initiatives, including STEM Innovation Networks Program, STEM Virtual Learning Network, STEM Master Teacher Corps, STEM Teacher Pathways, and Effective Teaching and Learning: STEM (Robelen, 2013). He pledged to carry out the initiatives to cultivate STEM talents with intensified efforts. It is thus evident that the STEM curriculum plays a decisive role in the curriculum reform of the United States.

In his research "Enticing the Crouching Tiger and Awakening the Hidden Dragon: Recognizing and Nurturing Creativity in Chinese Students", the scholar Wu (2001) recommended twelve crucial ways to nurture creativity, such as "adopting the confluence approach or interdisciplinary perspective to cultivate creativity", "employing the theory of multiple intelligences as a framework to cultivate creativity", "valuing the assessment of both

diversity and authenticity, individuals and groups as well as experience and products” and “infusing creativity into the teaching of different disciplines and the curriculum integration” The Guidelines of 9-year Integrated Curriculum of Nature and Living Technology also emphasized that “the learning of nature and living technology should center on learners’ activities and focus on the open architecture and the subject-oriented method” (Ministry of Education, 2002). One proper way to nurture creativity is to involve students in experiential activities that encourage active exploration through interdisciplinary curriculum integration and an orientation toward open and diversified subjects. STEM project-based learning, based on constructivist teaching theory, integrates interdisciplinary knowledge of science, technology, engineering and mathematics via project-based learning strategies; provides students with a learning situation in which they can actively explore real experiences and design solutions to real-life problems to foster creative thinking and hands-on skills; adopts diversified evaluation so that students can give full play to their talents; exposes students to engineering-related science and technology; and enables students to interconnect their classroom with the real world (Lee & Lee, 2014; Lou, Tsai, & Tseng, 2011).

Through STEM project-based learning, the current study guided students to explore nature and thereby spontaneously generated interest. It enabled students to creatively apply their knowledge and skills related to mathematics, natural sciences and other disciplines to scientific and technological activities to resolve simple real-life problems, and it offered learners a chance to verify their theoretical knowledge and achieve the unity of learning and practice. It also further examined the impact of STEM project-based learning on the cultivation of creativity. Two research purposes were specified:

- (1) to analyze junior high school students’ experience in STEM project-based learning and
- (2) to investigate how junior high school students’ involvement in STEM project-based learning influenced their creativity.

LITERATURE REVIEW

Science, Technology, Engineering and Mathematics & Project-based Learning (STEM & PjBL)

Science, technology, engineering and mathematics & project-based learning (STEM-PBL) is a model of teaching and learning that is based on the connotations of STEM education and integrated with the PBL curriculum design (Lou et al., 2011). As defined by the “Draft of the Implementation of STEM Teachers Standards”, STEM education is a method of teaching and learning that integrates the contents and skills of science, technology, engineering and mathematics. STEM teaching is guided by the standards of STEM implementation to elicit behavior that is expected to lead to proficiency in STEM. These behaviors include participation in investigations, logical reasoning and problem resolution. In one study, the goal of STEM education—i.e., to prepare students for post-secondary education and the working environment of the 21st century—was reached (Maryland State Department of Education,

2012). The STEM teaching model integrates science, technology, engineering and mathematics, enables students to grasp integrated knowledge, boosts students' interest in science and technology and thereby strengthens students' ability to address life problems.

The STEM curriculum is a course design integrating science, technology, engineering and mathematics (Lou, Chung, Dzan, Tseng, & Shih, 2013). Through this curriculum, students can acquire complete knowledge, become more skillful in addressing real-life problems and develop their critical thinking so that they will be more competitive for future employment. The principal purpose of STEM teaching is to improve the traditional lecture method, break the myth of the effectiveness of discipline-based teaching and diversify the teaching methods. It is vitally important that students be able to construct their own knowledge system instead of being spoon-fed. The main implementation strategies include (STEMTEC, 2000) cooperative learning, investigation-based learning, educational technology, and new assessment methods.

Through cooperative learning, educational technology, exploration-based learning and diversified assessment methods, STEM teaching enables students to demonstrate the spirit of teamwork, strengthen their team cooperation, evaluate and solve difficult problems they encounter in life, and improve their ability to master new knowledge (Lewis, 2006). In this way, students can nurture their creative spirit, grow their different talents under diversified assessment, interconnect the classroom with the real world and become well-prepared for their future work. However, STEM qualities are not the simple combination of scientific quality, technological quality, engineering quality and mathematical quality. Instead, the process of rote learning to memorize fragmentary knowledge is transformed into a process to explore the different yet interconnected aspects of the world (Scott, 2012). One feature of the STEM classroom in an "intellectually messy" learning situation, students are required to collect information, analyze data, and design, test and formulate a solution.

According to the above-reviewed literature, science aims to understand the world, explain the objective laws of nature, express and analyze various situational issues via mathematics and achieve technological innovation based on the respect for the laws of nature and by virtue of creative engineering design (Huang, Tsai, Diez, & Lou, 2014). This process of innovation entails a wide variety of qualities and abilities to resolve related problems. STEM curricula are designed to train these abilities, enhance the integration capability at all levels and strengthen students' creativity.

Mergendoller, Markham, Ravitz, and Larmer (2006) defined PBL as a systematic teaching method that helps students successfully acquire knowledge and skills by exploring complex subjects and carefully planned tasks in great depth. Project-based learning is a teaching and learning model that attracts students to learn via projects. Projects include research activities to make students concentrate on such complicated tasks as design, problem resolution and decision making (Tseng, Chang, Lou, & Chen, 2013). Students independently design real and feasible products or present their research accomplishments in their spare time (Fleming, 2000; Mergendoller & Thomas, 2001). The current study centered its course design on STEM project-based learning. It started with the scientific curriculum of life experience, and

Table 1. Connotations of 4Ps of Creativity

Dimension	Connotation
Process	"Creativity" is the entire phase prior to the rise of thoughts and even subsequent to the formation of concepts.
Person	Persons with "creativity" have certain unique personality traits.
Product	"Creativity" is the capacity to generate original, novel and valuable products.
Press/Place	The development of "creativity" is the product of the press and the environment.

it encouraged students to learn actively, explore all possible solutions and master useful and profound knowledge and skills during the hands-on production of project works. Eventually, students were equipped with internalized abilities rather than fragments of knowledge. STEM PBL has been defined to "specify vague work tasks in the interdisciplinary structure" (Stearns, Morgan, Capraro, & Capraro, 2012). Berry, Chalmers, and Chandra (2012) proposed three teaching models to help teachers implement the STEM PBL: the central project approach, the student-led projects approach, and the use of student-led projects as the curriculum.

As discovered by the present author, the STEM-PBL curriculum design mostly took physical concepts as the themes of activities and rarely took chemical concepts as the starting points. Therefore, from the chemical perspective, this study adopted the central project approach and selected the course theme related to daily life—the creative design of CaC₂ steamships—to arouse students' curiosity and learning motivation. During the hands-on process, students interacted with their partners and helped adjust and correct the conceptions of their teams. Students were instructed step by step through the exploration so that their knowledge and concepts could be combined with the real world and their STEM knowledge could be integrated and condensed effectively. The learning was thus made meaningful.

Related research on creativity

In 1961, Rhodes integrated different studies on creativity and summarized the definitions of creativity into four elements, called the 4Ps of creativity: process, person, product and press/place. The connotations of these 4Ps are listed in **Table 1**. Wu and Fan (2011) also suggested that creativity in educational policies should cover the connotations of these 4Ps of creativity, though its contents may vary by country and region. Research on creativity conducted at different time points has also revealed the main scope of these 4Ps of creativity and shown that they cover all manifestations of creativity.

The definition of creativity varies according to the theoretical basis, connotations and implications. It is hard to establish objective rating criteria, making creativity difficult to evaluate. In 1989, Hocevar and Bachelor analyzed more than one hundred tools and methods to evaluate creativity. Except for a few that could not be categorized, the remaining tools or methods to evaluate creativity could be roughly classified into 8 categories: (1) the divergent thinking test; (2) the study of outstanding people's traits; (3) self-reported creative activities or achievements; (4) the evaluation of others; (5) the personality scale; (6) the scale of interest and attitude; (7) the biographical questionnaire; and (8) the assessment of products or works. To

discover students' creative talents, the methods to evaluate creativity should be comprehensive and diversified and examine the way students ordinarily perform. Additionally, different studies may develop, select or apply the abovementioned evaluation methods or tools in accordance with their research questions. Among the commonly used creativity tests, the most famous ones are Torrance Tests of Creative Thinking (TTCT) and The Williams Creativity Assessment Packet revised by Lin & Wang (1994), which can be used to evaluate creative thinking. The Williams Creativity Assessment Packet has been extensively applied in the teaching activities of various domains, such as performing arts courses, music courses and science teaching, and most creativity-related studies have demonstrated positive results (Jin, Wang, & Dong, 2016; Li et al., 2014; Wang & Cheng, 2016).

Under the STEM structure, the current study assigned tasks to teams of students. The students went through the project-based learning process, i.e., perceiving the defects of problems, being aware of difficulties, seeking answers, suggesting hypotheses, verifying hypotheses, and finally creating unique and practical works. The curriculum design related to STEM PBL also complied with the relevant 4P theory of creativity. This study developed the "Creativity Tendency Scale" from the Williams Creativity Assessment Packet revised by Lin and Wang (1994) and investigated the research sample with this scale to reveal the influence of STEM PBL on students' creativity tendency.

RESEARCH METHODOLOGY

This study adopted a quasi-experimental method and selected 60 ninth-grade students via purposive sampling. In accordance with the heterogeneity of their academic achievements in grade 8, the selected students were divided into 12 mixed-gender groups and were seated in the classroom in an S-shape for experimental teaching to delve into the influence of STEM PBL on students' creativity.

Teaching design

This study developed "CaC₂ steamship STEM PBL activities" in accordance with PBL's five major processes of design and planning: 1. setting the goal first and then making the plan; 2. carefully designing the guidance problems; 3. evaluating the plan; 4. formulating the professional plan; and 5. managing the process. First, according to the curriculum goal, this study decided on the development objectives and concepts of PBL activities, used the CaC₂ steamship as the theme of creative design, and designed and planned the six-week learning activities. The concepts and connotations of science, technology, engineering and mathematics in the thematic CaC₂ steamship activities are shown in [Table 2](#). Accordingly, the CaC₂ steamship STEM PBL activities were designed. The activities were carried out in accordance with the five stages of STEM project-based learning mentioned in the literature review – preparation (for one week), implementation (for two weeks), presentation (for one week), evaluation (for one week) and correction (for one week) – which was the flow for learners to execute the project-based learning. According to this five-stage flow, the students' learning

Table 2. Concepts and Connotations of CaC₂ Steamship STEM PBL Activities

Science (S)	Technology (T)	Engineering (E)	Mathematics (M)
The concept of density	Selection of materials	Problem resolution	Calculation of density
The principle of buoyancy	Use of tools	Creative thinking	Calculation of
The concept of fluid	Ways of processing	Design of modeling	buoyancy
The concept of thermal energy	Testing, adjustment and	Structural design	Calculation of load
Methods of heat transfer	correction	drawing and	Calculation of speed
Newton's Laws of Motion		graphing	

feedback forms were designed for these five stages to help them complete the CaC₂ steamship STEM PBL activities.

Research tools

This study mainly used two tools to collect data, i.e., the “interview outline” and the “Creativity Tendency Scale”, introduced as follows.

Interview outline

After students had participated in the STEM PBL curriculum, a semi-structured interview was conducted to further explore the interactions among group members in the STEM activities as well as the STEM learning and application of works. The interview outline consisted of four parts: (1) the design ideas of STEM activities, (2) the forms of group interaction in the STEM activities, (3) the problem-solving models in the STEM activities, and (4) the STEM learning and application of the characteristic works of each group. The abovementioned data were obtained mainly through the students' learning feedback forms and interview materials and based on the teacher's observation. The data were then encoded, classified, constructed, analyzed and summarized according to the nature and focus of this study.

The Creativity Tendency Scale

The contents comprised four aspects: adventurousness, curiosity, imagination and challenge. Regarding validity, the correlation coefficients of all scores ranged between .502 and .588, all of which reached the level of significance. Regarding the test-retest reliability, the correlation coefficients ranged between .489 and .810, reaching the level of significance (121 students comprised the sample, including 37 from grade 7, 38 from grade 8 and 46 from grade 9; the time interval between two tests was three to five weeks). Regarding the internal consistency reliability, the Cronbach's α of all scores ranged between .401 and .780. The abovementioned data were collected, classified, encoded and filed. SPSS 19.0 was used for descriptive statistical analysis, and a t-test analysis was performed for dependent samples.

DATA RESULTS AND ANALYSIS

This study collected data about the students' experience in learning activities for a qualitative analysis and description. Then, it analyzed the scores of the Creativity Tendency



Figure 1. The Design Drawing for the Drainage Mechanism Made of the Iron Drug Box

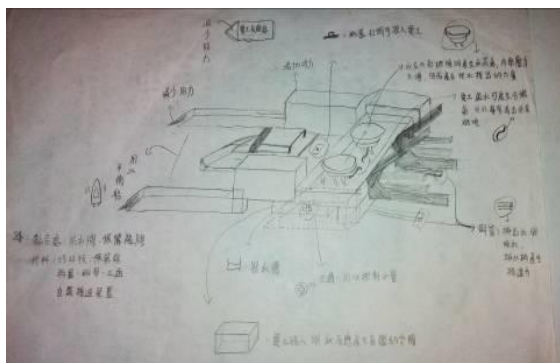


Figure 2. The CaC₂ Steamship Design Drawing

Scale for a quantitative analysis to investigate the effect of STEM project-based learning. The results and analysis are reported as follows.

Analysis of STEM PBL experience

Students' response to the STEM project-based learning and teaching model was explored through the researcher's observations. First, this study analyzed students' learning feedback forms and performed interviews with them. It summarized the specific relationships between the students' behavioral performance and the cognition and affection of their creativity in the five main stages of project-based learning. Second, this study analyzed the STEM connotations of the students' creative design works to identify what STEM-related knowledge the students had applied during their design of works. The interviews were encoded, and an example is follows: for I01, "I" indicates interview, and 01 symbolizes the students of the first group.

Creativity analysis of the PBL experience

1. The stage of preparation – the teacher guided the students to understand the theme and aroused their learning motivation.

The teacher introduced the thematic scope and resource limitations of the CaC₂ steamship and connected the curriculum theme with the students' prior knowledge to improve the fluency of their thinking. For example, as expressed by I01, *"The teacher introduced the history of ship evolution in class. We found that the ancient ships were mostly made of wood."* Furthermore, the teacher grouped the students and instructed them to divide the group tasks among all group members and to specify responsibilities, such as collecting and sorting out network information, collecting materials and producing design drawings to nurture the flexibility of their thinking. As mentioned by I02, *"Someone suggested using the English word for 'steamship' to search for different drainage mechanisms on the Internet. We decided to produce our drainage mechanism by drilling a hole in the iron drug box and connecting it to the copper pipe."* as shown in **Figure 1**. Finally, the teacher proposed situational hypotheses to cultivate the originality of their thinking as stated by I01: *"Regarding the materials to make the body of the ship,*



Figure 3. The Design of Water Inlet Control for the Dropper

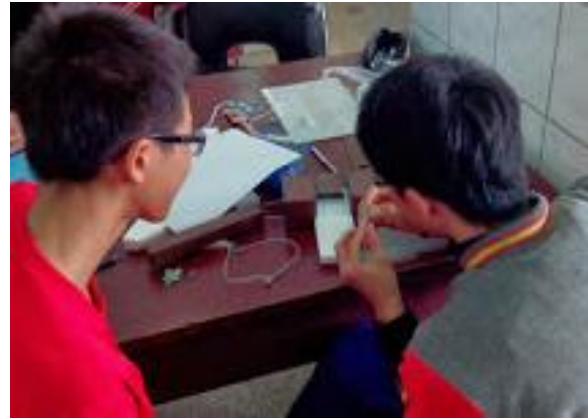


Figure 4. Practical CaC₂ Steamship Tests



Figure 5. The Double-Dropper Design

most of the groups used the milk box and Styrofoam. But our group wanted to be unique, so we chose the bamboo.", and to inspire the students' imagination for the CaC₂ steamship design drawings, as shown in **Figure 2**. The students then set out to collect information and prepare materials.

2. The stage of implementation – the students were the main actors to strengthen their hands-on ability and problem-solving competence.

This stage emphasized helping the students clearly understand their own design conceptions and reasons. As stated by I02, "We have measured the water inlet speed of the dropper. It can be used as the design of water quantity control." as shown in **Figure 3** and equipping the students with strong flexible thinking to practically actualize their own ideas and design drawings. As mentioned by I05, "We utilized the aluminum can, plastic steel soil and bendable straws to comprise the drainage pipe, which exactly accorded with our conception of light-weight design." Therefore, the students were required to produce their works according to their design drawings and to conduct actual tests, as shown in **Figure 4**, to validate whether the CaC₂ steamship property conformed to the design. Moreover, the students were asked to further analyze why they failed to reach their goal, identify the problems and think of proper ways to



Figure 6. I09 Presentation of the CaC₂ Steamship Accomplishments



Figure 7. I03 Presentation of the CaC₂ Steamship Accomplishments

resolve these problems. As stated by I06, *“The deficiency of the dropper lied in the limited amount of water it could hold. To ensure our ship can finish the whole journey successfully, we decided to adopt the double-dropper design, which could be well matched for modeling.”* as shown in **Figure 5** to enhance the fluency and flexibility of their thinking.

3. The stage of presentation – the students were trained to foster their capacity to summarize key points and express themselves.

At this stage, the students played the leading role. Group by group, they presented the design ideas of their CaC₂ steamships and the applied STEM-related knowledge, and they shared the problems they encountered during the practice and their solutions. The students were offered the chance to practice displaying their thoughts in words. As stated by I09, *“It is really not an easy task to clearly explain our thoughts and innovative design ideas in words.”* as shown in **Figure 6** and summarizing key points and briefly reporting their actual experience. As described by I03, *“I was really nervous when I gave the brief report on the platform for the first time. I made it thanks to my good preparation.”* as shown in **Figure 7**.

4. The stage of evaluation – the diversified evaluation mechanism helped the students think more meticulously and thoroughly.

This stage consisted of expert evaluation, peer evaluation and self-evaluation. For expert evaluation, two experts in natural sciences were invited to serve as the judges and comment on the creative design ideas and accomplishments of all groups. For instance, Expert A commented that *“the source of fire was too big, and it could easily cause the plastic articles on the ship to be melted.”* Expert B held the view that *“resistance could be easily formed when the CaC₂ container was placed under water, so a streamlined container should be used.”* For the peer evaluation, all students were required to evaluate each other’s work by group and record the advantages and disadvantages of different groups’ works on the peer evaluation form. For example, I02 stated that *“the design of the gravity center of the ship body was neglected, causing the inclination of the ship center”*, and I12 offered that *“if the dripping controller was placed horizontally, the water could not run into the container smoothly.”* For self-evaluation, after the presentation, the students of all



Figure 8. Before Correction



Figure 9. After Correction

groups were asked to share their reflections on the activities and note what needed to be improved to challenge themselves and break through the current state. These evaluation mechanisms were employed to upgrade the elaboration and flexibility of their thinking.

5. The stage of correction – the students were encouraged to make corrections according to the feedback and suggestions and improve their own abilities.

At this stage, it was expected that the students could self-critique their works according to the suggestions proposed during the evaluations of experts and peers. As shown in **Figure 8**, the defects of the ship gravity center inclining forward and the watercolor painting dissolving in the water were used as the reference for the students' work correction. The students were encouraged to improve themselves and optimize their work. As shown in **Figure 9**, the water supply design was narrowed to balance the gravity center of the ship body. I01 and I05 said, *"The comments of experts and fellow students shed light on the blind spots of our design. Proper correction made our creatively designed works perfect."* In this way, the students were guided to practice flexible thinking and cultivate the personality traits to adventure courageously and challenge themselves.

The above analysis reveals the connection between the student groups' actual performance in all learning stages and their creativity. The analysis of students' feedback revealed that the "project-based" teaching model involved the students in the repeated PBL processes of preparation, implementation, presentation, evaluation and correction. It was greatly beneficial to the improvement of the students' ability in design and production as well as the cultivation of their creativity. Moreover, project-based learning used objects in daily life to arouse students' curiosity. When a group encountered certain problems, most members came up with possible ideas (imagination and fluent thinking) based on their past experience or personal thoughts. Later, through peer discussion, the group members assisted the group in adjusting and correcting their conceptions (adventurousness, challenge and flexible thinking). The group further materialized their conceptions (elaborate thinking) to validate the feasibility of such conceptions. During the materialization of conceptions, brainstorming in the group not only provided the students with a chance to learn with people who had different

abilities and specialties but also sparked more creativity (original thinking) during the interaction. As revealed by the observation and analysis of all stages, the PBL experience fostered the students' ability in peer discussion, communication and expression, teamwork, and effective thinking for the planning and production of work and improved their affective and cognitive creativity.

Analysis of STEM connotations of PBL experience

To understand the students' work design process and ideas, this study conducted semi-structured interviews with the groups that produced excellent work after the activities came to an end. The interview outline was drafted based on the STEM design features of the work of the groups. Their design details and STEM connotations were analyzed. The interviews revealed that the students could integrate the STEM connotations into their work according to the planning of these activities while designing creative work. The STEM connotations were elaborated as follows.

1. Science – the students learned to deepen their theoretical knowledge about science and increase the feasibility of their innovation.

The teacher instructed the students to apply science-related knowledge and process, such as physics, chemistry, biological sciences and earth sciences, to their work design. First, the teacher introduced the raw material of CaC_2 steamships, " CaC_2 ", to familiarize the students with the nature and application of CaC_2 . I06 said, "*Calcium carbide is a kind of mineral soil. It contains the chemical component of CaC_2 . It involves two chemical equations: $\text{CaC}_2 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_2 + \text{Ca}(\text{OH})_2$ and $2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}$.*" I11 mentioned, "*Calcium carbide is so amazing. It can have a chemical reaction with water, which produces C_2H_2 . The combustion of C_2H_2 generates flames, making it the tool for lighting in the early times.*" The students were asked to extend their learning and apply their knowledge based on the chemical nature of calcium carbide. Carbon dioxide and steam can be produced by combusting C_2H_2 and oxygen. The students were then guided into the thematic " CaC_2 steamship"-derived activities. As observed, the majority of the students combined their thoughts with theories during the STEM learning. For example, I01 reported, "*When testing the drainage pipe by adding water, we found that the ship body was too heavy. So we tried using Styrofoam to increase the buoyancy of the ship (density and principle of buoyancy).*" I03 stated, "*Combustion will produce heat, so we should avoid the problem that the foam board will melt when it encounters heat (thermal energy and heat transfer).*" I05 mentioned, "*The chemical reaction between calcium carbide and water is used to produce steam. The action and reaction forces can be applied as the power for sailing (Newton's Third Law of Motion).*" As the theoretical knowledge became rooted in the students' mind, their innovative application would become more feasible.

2. Technology – the students were trained to improve their technological qualities and tap their potential to innovate.

The teacher taught the students to use technology, understand the development of technology and master the ability to analyze new technology. For instance, I02 stated, *"Lightweight materials should be selected. Styrofoam is a good option."* I04 mentioned, *"After discussion, we selected the foam board for our steamship because the foam board was light but with great buoyancy, and it was convenient to cut and assemble foam boards."* The observation of the students' material selection showed that most of them could choose proper materials and fully display the properties of the chosen materials by repeated tests, adjustments and corrections. For example, I03 said, *"We can combine the bamboo and Styrofoam as the material of our ship body."* I07 stated, *"According to our design drawing, we combined the PET bottle and the foam board in a creative manner as the main material of our ship body."* Consequently, the students were trained to develop technological qualities, comprehend the connotations of newly emerging technology, unleash more creative potential and enhance the capacity to innovate.

3. Engineering – the students were helped to internalize their knowledge about engineering design and improve their problem-solving abilities.

The teacher closely connected difficult concepts with the students' real life and helped them gain a better understanding of technological engineering design and development processes. I04 stated, *"After the teacher explained the application of calcium carbide to daily life, we understood the properties of calcium carbide better. And it was helpful for our creative steamship design."* The analysis of the students' experience in STEM PBL activities revealed that when faced with difficult problems, students sought solutions by mutual discussion, consulting the teacher or searching for information on the Internet. Then, they repeatedly tried to find the solutions. I06 mentioned that *"the double-dropper water supply design could improve the water flow rate control and make C_2H_2 fully combusted."* In addition, the students were able generate unique modeling by creative thinking when they improved problems, as noted by I09, who stated, *"We designed our ship body in the shape of shark in order to reduce the resistance under water."* Therefore, the students were trained to internalize their knowledge about engineering design and encouraged to address problems bravely and creatively. This sharpened their problem-solving capacity.

4. Mathematics – the students were encouraged to apply mathematical methods and practice elaborate thinking.

The teacher encouraged the students to willingly analyze, infer and experiment on related mathematical problems when they discovered them. For example, I05 said, *"We can apply the mathematical concepts of sector and circular cone to our works."* I01 stated, *"We used the buoyancy principle that we had learned before to calculate the load capacity of our ship."* I08 stated, *"We applied the simple chemical measurement to roughly evaluate the reaction time of calcium carbide and thus could grasp the speed of sailing."* Therefore, the students were encouraged to try as many mathematical methods as possible. They obtained related data by calculation and completed the experiment records, by which they were trained to develop the elaboration of thinking.

Table 3. The Pretest and Posttest of Creativity Tendency Scale

Item		Number	Mean	SD	t
Imagination	Pretest	60	26.68	4.47	4.03**
	Posttest	60	28.28	5.15	
Curiosity	Pretest	60	28.70	4.59	3.79**
	Posttest	60	30.45	4.10	
Challenge	Pretest	60	27.03	3.91	3.47**
	Posttest	60	28.55	3.58	
Adventurousness	Pretest	60	26.27	3.43	3.05**
	Posttest	60	27.22	3.17	

$p^{**} < .01$

In conclusion, this study discovered that the creative STEM design of all groups was sourced from the students' new findings during their hands-on process or what they had learned from imitation, combined with their creative refinement. It revealed the importance of the integration of science, technology, engineering and mathematics and the design of hands-on curricula. Through the curriculum planning, the students were guided to begin with integrated STEM thinking, detect problems in practice and obtain new inspirations to solve problems. These innovative ideas also brought the students a sense of achievement, further motivated them for creation, and rendered them more immersed in the learning of new knowledge.

Analysis of the development of the affective aspect of creativity

Before and after the STEM PBL experimental teaching, the students received the pretest and posttest of the Creativity Tendency Scale. Their scores were used as the basis to analyze the affective development of creativity. This test was consisted of four sub-tests about imagination, curiosity, challenge and adventurousness. A paired-sample t-test was conducted on the obtained data, as shown in [Table 3](#). After they were involved in the STEM project-based learning, students' affective aspects of their creativity, including imagination, curiosity, challenge and adventurousness, were significantly improved. The results are reported as follows.

Imagination

The average score increased by 1.60 points – from 26.68 points on the pretest to 28.28 points on the posttest – as shown in [Figure 10](#). Through the t-test, the difference between the score of imagination in the pretest and that in the posttest reached the level of significance ($t=4.03, p<.01$). This demonstrated that at the stages of preparation and implementation of the STEM PBL curriculum, the students came up with their own design drawings and repeatedly carried out validation, testing and analysis, which improved their imagination.

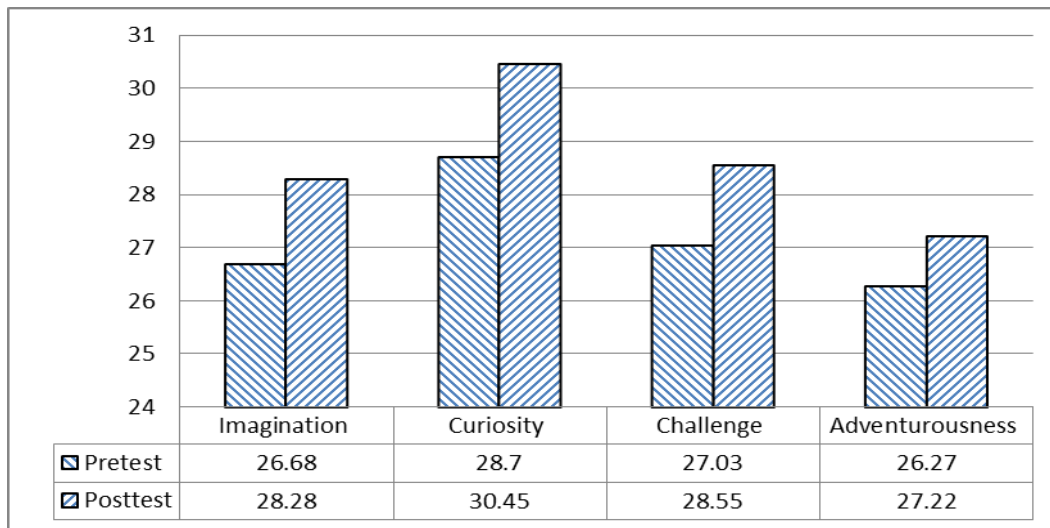


Figure 10. The Comparison of the Average Scores of the Pretest and Posttest of Creativity Tendency Scale

Curiosity

The average score increased by 1.75 points—from 28.70 points on the pretest to 30.45 points on the posttest—as shown in **Figure 10**. Through the t-test, the difference between the score of curiosity in the pretest and that in the posttest reached the level of significance ($t=3.79$, $p<.01$). This revealed that the STEM PBL curriculum design was based on objects in daily life to arouse the students' learning motivation, and students addressed difficulties by hands-on practice, which enhanced their curiosity.

Challenge

The average score increased by 1.52 points—from 27.03 points on the pretest to 28.55 points on the posttest—as shown in **Figure 10**. Through the t-test, the difference between the score of challenge in the pretest and that in the posttest reached the level of significance ($t=3.47$, $p<.01$). This showed that the students managed to get a clue in the complicated preparation stage and sought more possibilities. In the correction stage, they made corrections in accordance with peer and expert evaluations and self-critique their own works, which improved their ability to take on challenges.

Adventurousness

The average score increased by 0.95 points—from 26.27 points on the pretest to 27.22 points on the posttest—as shown in **Figure 10**. Through the t-test, the difference between the score of adventurousness in the pretest and that in the posttest reached the level of significance ($t=3.05$, $p<.01$). This shows that at the implementation stage of the STEM PBL curriculum, the students must suggest bold hypotheses and design experiments based on the collected

materials. Even at the correction stage, they bravely accepted the criticism of peers and experts and fulfilled their tasks by correcting defects, which strengthened their adventurousness.

CONCLUSIONS AND SUGGESTIONS

After facilitating CaC2 steamship STEM PBL activities, this study analyzed the students' learning experience in five stages – preparation, implementation, presentation, evaluation and correction – to explore the influence of STEM PBL on the students' creativity and ability in STEM learning and application. The key points of all these stages are summarized. (1) The stage of preparation: the teacher guided the students to understand the theme and aroused their learning motivation. (2) The stage of implementation: the students acted as the main actors to strengthen their hands-on ability and problem-solving competence. (3) The stage of presentation: the students were trained to foster their capacity to summarize key points and express themselves. (4) The stage of evaluation: the diversified evaluation mechanism helped the students think more meticulously and thoroughly. (5) The stage of correction: the students were encouraged to make corrections according to the feedback and suggestions and improve their own abilities. In summary, after participating in the STEM project-based learning, most students agreed that the design of these activities could improve their creativity and ability in STEM learning and application.

By integrating the STEM curriculum structure and activity design, this study analyzed the connotations of STEM PBL and summarized the STEM learning objectives. (1) Science: the students learned to deepen their theoretical knowledge about science and increase the feasibility of their innovation. (2) Technology: the students were trained to improve their technological qualities and tap their potential to innovate. (3) Engineering: the students were helped to internalize their knowledge about engineering design and to foster the problem-solving ability. (4) Mathematics: the students were encouraged to apply mathematical methods and practice elaborate thinking. In conclusion, the students were guided to detect problems from practice and learn from mistakes. Through group discussion, they found coping strategies to resolve problems. The implementation process of activities exposed them to the importance of team cooperation.

Regarding the development of the affective aspect of creativity, the experimental results showed the significantly positive influence of STEM PBL on the affective development of creativity, including adventurousness, curiosity, imagination and challenge. The results also revealed the students' potential interest and curiosity to explore science knowledge and things. The STEM PBL curriculum was designed based on objects in daily life, giving free rein to the students' imagination for creative design. The hands-on practice challenged their personal limits, nurtured their adventurous spirit, aroused their learning motivation and finally improved their creativity.

To sum up, project-based learning aims to improve the deficiencies of traditional teaching. STEM offers students a chance to accumulate experience in hands-on practice, and it

enables them to integrate and apply related knowledge of science, technology, engineering and mathematics in the situation of “learning by doing and achieving enlightenment from mistakes”. Therefore, this paper suggests teachers should design hands-on activities that are student oriented and based on life experience and social issues because this will strike a chord with students and arouse their learning motivation and thereby improve their creativity. Moreover, teachers should create the proper design and plan before implementing STEM PBL teaching activities. They can refer to the five stages—preparation, implementation, presentation, evaluation and correction—analyzed in this study to provide students with integrated STEM activities of creative learning. They can also provide students with a more diversified STEM learning environment from the perspective of chemical theories according to the CaC2 steamship STEM PBL activities designed by this study. Additionally, by dividing the students into high-score and low-score groups in line with their previous academic achievements, future research can further probe the difference between the performances of these two groups in STEM project-based learning to provide a basis for STEM PBL activity improvement.

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