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An Assessment of Junior High School Students' Knowledge, Creativity, and Hands-On Performance Using PBL via Cognitive–Affective Interaction Model to Achieve STEAM

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Abstract: This study aimed to discover the implications of using different teaching approaches for a hands-on STEAM activity for junior high school students' STEAM knowledge, creativity, and hands-on performance. The teaching contents used in the study were designed based on the project-based learning (PBL) strategy and the cognitive–affective interaction model (CAIM). The students' learning outcomes were tested through a hands-on activity with the theme of electric boat creation. PBL with the CAIM was the strategy used to implement the hands-on STEAM activity and to achieve the United Nation's Sustainable Development Goal 4 (SDG 4). In this study, a quasi-experimental design was used for 10 weeks, and the 366 students who participated in the experiment were divided into experimental groups (EGs, 199 students using PBL with the CAIM) and control groups (CGs, 167 students using PBL only). Through the analysis of covariance, the results showed that students in the EGs achieved higher academic performance in terms of STEAM knowledge, creativity, and hands-on performance. The study also found that the hands-on STEAM activity had a positive effect on creativity for students in the EGs, allowing them to develop different modes of thinking in the processes of designing and producing the finished product, which in turn enhanced the innovativeness of their products and solutions. In addition, using PBL with the CAIM in the hands-on STEAM activity brought about positive learning outcomes and creative abilities for the students, achieving the SDG 4 objectives. Moreover, the outcomes of this study are in line with the current international trend in the development of education, providing reference examples for the future development of STEAM activities and teaching materials at the junior high school level.

Keywords: STEAM education; project-based learning (PBL); cognitive–affective interaction model (CAIM); creativity; Sustainable Development Goal 4 (SDG 4); hands-on performance

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1. Introduction

In recent years, great emphasis has been placed on issues related to science, technology, engineering, and mathematics (STEM) education in the field of education worldwide [1]. In particular, according to the 2019–29 Employment Projections released by the U.S. Bureau of Labor Statistics, the number of jobs in STEM-related occupations will increase by 8.0% by 2029, while the growth rate of all occupations will be 3.7% [2]. The European Union (EU) has also projected that the number of STEM-related jobs will increase by more than 12% by 2025, accounting for about 3.8% of all EU jobs [3].

The application of STEM education is one of the best ways to achieve the United Nation's (UN) Sustainable Development Goal 4 (SDG 4), which aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" [4]. Hands-on STEM activities allow students to combine science, technology, engineering, mathematics, and other disciplines with appropriate learning methods to cultivate their self-efficacy, problem-solving skills, and learner-centered skills [5,6]. However, some scholars have suggested that there is still room for improvement in STEM education, in which arts and humanities should be incorporated to achieve more balanced STEM learning overall [3,7]. This idea led to the creation of the term STEAM (science, technology, engineering, the arts, and mathematics). The realm of the arts includes aesthetics, creative thinking, design, and so on. After the integration of the arts, the realm of STEAM has become more relevant to life. Many studies have also shown that incorporating the arts into STEAM has enhanced the effectiveness of cross-disciplinary learning [8–10]. Moreover, through the emphasis on the integration of engineering education with human aesthetic imagination and innovation, novel products that transcend traditional values can be created, thereby enhancing students' creativity and improving their hands-on performance [11]. Therefore, compared with STEM education, the integrated STEAM education approach is more diversified and interesting.

Project-based learning (PBL) has become increasingly well developed in engineering education in recent years. The curriculum focus on student-centered learning and problem solving through teamwork, with an emphasis on solving real-life problems and developing students' active learning and problem-solving skills, allows students to investigate and discuss problems [12,13]. The key component of PBL is in-depth questioning [14]. Incorporating PBL into STEAM education not only strengthens learning outcomes but also enhances students' aptitude in STEAM [15], as the curriculum integrates knowledge, concepts, and skills for future careers [16,17]. For example, Hanif et al. [18] pointed out that project-based learning in STEM education helps improve students' creativity and their scientific achievement; thus, PBL can be used as an alternative teaching strategy in junior high schools.

In view of the essential abilities in today's society, students deserve training in creative thinking ability, shifting from traditional teaching and standardized testing to a more creative learning model [19,20]. Many studies have also found that creativity can be enhanced through training in creative thinking, which develops students' abilities in creative and deliberate thinking [21,22]. Williams [23] proposed the cognitive–affective interaction model (CAIM), believing that creative students are able to solve various problems in their lives through creativity. Some studies have also pointed out that through creative teaching, teachers can stimulate the creative potential of their students [24,25]. Many courses and teaching approaches for creativity are commonly used in STEAM education. However, due to the diversity and complexity of creativity [26], many teachers have difficulty in deciding on the form of creativity curriculum to be incorporated into their STEAM courses [9]. Therefore, PBL with the CAIM was chosen for the hands-on STEAM activity in this study to investigate its effects on students' creativity.

Past studies have found that most teachers use commercially available STEM/STEAM curriculum kits (ex. LEGO kit) for teaching in order to meet the trend of STEM/STEAM education [27,28]. However, most of these kits tend to focus on the cognitive aspects of a single subject, lacking teaching materials for cross-disciplinary learning. On the other hand, the designs for affective learning in terms of learning attitude, motivation, and creativity are also inadequate. Using technological tools and hands-on activities to develop skills has been neglected as well [29,30]. Therefore, this study aimed to raise the cognitive level of junior high school students through a STEAM course to stimulate their high-level creative thinking and strengthen their technological and vocational skills, which are also related to SDG 4 objectives [4].

As stated above, the researcher used PBL with the CAIM as the teaching strategy to investigate its effects on STEAM knowledge, creativity, and hands-on performance in junior high school students, with "Making an Electric Boat" as the theme of the teaching activity. An electric boat consists of many common scientific principles, such as buoyancy, force, and motion, as well as location and the measurement of the center of gravity. The STEAM course was closely aligned with the learning contents of Grade 9 Mathematics and

Science, while the hands-on activity involved the application of engineering knowledge, including motors, electric current, and Arduino electronic components. The design of the hull required the consideration of different materials and shapes, and through creative design thinking, the students had to identify various problem-solving models, which met the objectives of SDG 4 education through the STEAM hands-on activity. At the same time, the CAIM was included in order to stimulate the students' creativity, allowing them to design and create innovative electric boats. The research questions of this study were as follows:

(1) How to design a hands-on STEAM activity that incorporated PBL with the CAIM?
(2) Did different teaching strategies (i.e., PBL with the CAIM vs. PBL only) make an impact on students' STEAM knowledge, creativity, and hands-on performance?

2. Literature Review

2.1. STEAM Education

STEAM is a cross-disciplinary teaching approach that combines science, technology, engineering, the arts, and mathematics. With a foundation of mathematical logic, students can learn about science and technology through hands-on construction projects that present the aesthetics of the arts [10]. Under the cross-disciplinary teaching framework, students can emphasize a particular topic of interest instead of being limited to a single subject. They can also exercise thinking from different perspectives and develop their skills in multiple disciplines in diverse ways [8,31]. Based on a report from the National Academies of Science, Engineering, and Medicine: (1) STEAM can help students have more positive learning outcomes; and (2) curriculum integration of STEAM can enhance the scientific and technological literacy of students in the Arts and Humanities. Unlike information-based education that exists on paper or on the blackboard, STEAM education allows students to learn how to think and develop linkages between the knowledge they gained and the real world [32].

In an era of globalization with rapid technological development, innovations in technology have become increasingly important. Knowledge and skills related to STEAM are required in nearly all innovative fields and occupations. The future trends in K-12 education will emphasize programing and robotics, hands-on activities, 3D printing, and animation software together with the integration of STEAM learning, encouraging the cultivation of creativity across various disciplines [29,30]. The ultimate goals of STEAM education are to nurture cross-disciplinary future talents and enhance their competitiveness in terms of global trade, technology, and education. If essential skills and abilities can be combined with their corresponding STEM/STEAM-related occupations in education, a great impact will be triggered on students' choices of their future careers [33]. In light of this, the development of a hands-on STEAM activity was the main focus of curriculum design in this study.

2.2. Project-Based Learning

PBL is a teaching method based on constructivist theory, allowing students to engage in problem-solving activities and cross-disciplinary curricula, answer open-ended questions, and achieve curriculum objectives through hands-on activities and group activities [34]. In 1997, Pellegrinelli [35] proposed the five phases of PBL to the Educational Innovation Groups (EIG) established at the Technical University of Madrid: (1) Initiation; (2) Definition and Planning; (3) Projects Delivery; (4) Renewal; and (5) Dissolution. Pellegrinelli [35] believed that the roles of teachers in PBL curricula should provide multiple ways of thinking, encouraging students to keep pondering problems in order to understand and solve them, integrating the course content, and facilitating teamwork. In recent years, the PBL teaching strategy has been gradually adopted in the fields of science and engineering. It has been proven that PBL can enhance students' learning ability, knowledge application, problem-solving skills, and participation in teamwork. Moreover, students' learning attitude can improve during the discussion process [7,15,31]. Many research works on teaching and learning have demonstrated that incorporating PBL into STEM/STEAM education can arouse students' interest in learning. For example, Kuo et al. [31] stated that combining PBL with STEM can increase students' creativity and can have a positive impact on their learning by enhancing their learning interest and self-efficacy. The study by Adriyawati et al. [36] used a STEAM project-based learning approach to teach the topic of alternative energy to elementary school students, and the results showed that PBL promoted scientific awareness in the students and cultivated their curiosity and problem-solving ability, making them more confident in raising questions.

Summarizing the literature cited, the hands-on STEAM activity used in this study was designed based on the five phases of PBL proposed by Pellegrinelli [35], which would enable the students to understand the application of their subject knowledge and various tools to finish their product. PBL would also enable the students to design and create a complete electric boat by integrating the knowledge acquired in different disciplines.

2.3. Creativity

In this study, creativity is defined as an ability that can be enhanced through study and training [37]. Guilford [38] first proposed the concept of "creativity" in 1950, in which he described it as the ability to invent or create something unprecedented. In 1977, he also developed the Structure of Intellect (SOI) model, which states that divergent and convergent thinking practices and training should be incorporated into instruction in order to stimulate creativity [26]. Based on Guilford's theory, Williams [23] further stated that cognitive and affective behaviors in the classroom setting are essential for stimulating creativity. With appropriate tools for measuring cognitive and affective skills, students' progress in creativity development can be monitored [23]. Therefore, this research on creative teaching was mainly based on the CAIM developed by Williams, which comprises 18 strategies [23]. Williams [23] proposed that there were three dimensions. The first dimension is courses, which included six subjects, such as art, music, natural science, social studies, mathematics, and language. The seconded dimension is teaching strategies, which included eighteen strategies, such as parodoxes, attributes, analogies, discrepancies, provocative questioning, example of change, example of habit, organized random search, skills of search, tolerance for ambiguity, intuitive expression, adjustment to development, study creative people and process, evaluate situations, creative reading skill, creative listening skill, creative writing skill, visualization skill. The third dimension is learners' behaviors: cognitive divergent thinking, including fluency, flexibility, originality, elaboration; and affective motivations, including risk taking, curiosity, imagination, complexity. With Creativity Assessment Packet (CAP) tools for measuring cognitive and affective skills, students' progress in creativity development can be monitored [23].

Many teaching strategies and activities in creative teaching can provide students with room for imagination and stimulate them to think in different ways [25,37]. Due to the theoretical completeness of CAIM, the clear strategies, and the well-developed questionnaire, the study used CAIM as the framework of creativity, and it used the CAP to evaluate the students' creative performance. The researchers analyzed the above eighteen teaching strategies and found out that there are five appropriate strategies for integrating PBL in STEAM Education, namely example of habit, provocative questioning, skills of search, example of change, and evaluate situations. The researchers used those five strategies in the study. The researchers also had discussions with several specialists on integrating various five phases of PBL with creative teaching, including a high school mathematics teacher, a high school physics teacher, and three living technology teachers in junior high schools. Table 1 lists the corresponding results and the reasons for the fit between PBL and the CAIM strategies.

Table 1. Correspondence and the reasons for the fit between PBL and the CAIM.

PBL Phases	CAIM	Reasons for the Fit
Initiation	Example of habit	This stage is about identifying habitual thinking and using "example of habit" to change students' deep-rooted patterns of thinking in the past, which will help them to reframe and explore issues.
Definition and Planning	Provocative questioning	As the most important stage of PBL, this stage allows students to think deeply in many different ways. "Proactive questioning" can be used to provoke students' high-order thinking.
Projects Delivery	Skills of search	This stage emphasizes group discussions. "Skills of search" can be used to establish experimental or simulated environments for students to observe and explore together.
Renewal	Example of change	Teachers act as the facilitators in this stage. They do not dominate the discussion during the PBL process, but they will offer help to students if necessary. When there is a bottleneck or a mistake in the students' discussion, teachers can give direction using an "example of change" to help them tackle the problem from a different perspective.
Dissolution	Evaluate situations	This is the stage in which teachers listen to the presentation of the results of each group and give feedback. Teachers can use "evaluate situations" to point out the shortcomings of students' discussions and give suggestions.

Note: Researcher's own compilation.

2.4. Hands-On Activities

Hands-on activities have long been recognized as a key factor in motivating students to learn [39]. Students can learn to think systematically through trial and error, and hands-on learning processes can enhance students' motivation and learning outcomes [30]. According to Dale's learning pyramid, students can achieve 75% of knowledge uptake through hands-on activities and 100% uptake through the immediate application of what they learned [40]. Hands-on skills can strengthen students' ability to integrate their knowledge and apply it. Through design and hands-on activities, students can integrate their knowledge acquired in various subjects, appreciate the link between theory and real life, and have the opportunity to perform hands-on activities [41].

Students' ability in creative designs affects the innovativeness of their products produced in the hands-on process. Their problem-solving ability can also be cultivated by creativity training [30,42]. Therefore, the creative product analysis matrix (CPAM) proposed by Besemer and Treffiger [43] was adopted in this study. Different attributes of students' products are evaluated through a variety of assessment criteria in different categories. After multiple tests and adjustments, the CPAM has been cited many times in assessing hands-on products in various fields that emphasize hands-on activities, including engineering education [12,13], product design [44], science education [30], and 3D modeling design [29]. The CPAM comprises three different dimensions: Novelty, Resolution, and Elaboration and Synthesis. "Novelty" stresses the use of novel materials, processes, concepts, and methods in the production of products. "Resolution" refers to the quality, feasibility, and functionality of the products. "Elaboration and Synthesis" emphasizes the level of detail and hands-on activity of the products.

3. Materials and Methods

3.1. Participants

This study adopted purposive sampling to select students from Grade 9 in a junior high school in Taipei. Consent forms for teaching experiments were obtained from the parents of the students before the experiments were conducted to ensure the ethics of the study. Since this study was conducted on a class basis, it was not possible to split the classes evenly for the experimental groups and the control groups, so the number of students in each group varied. In the current study, the experimental groups (EGs) comprised five classes (i.e., 199 students who used PBL with the CAIM), while the control groups (CGs) comprised four classes (i.e.,167 students who used the PBL strategy only). There was a total of 366 participants (172 females, 194 males; aged between 15 and 16 years old) (see Table 2).

Table 2. Participant distribution.

Groups	Experiment Design	No. of Students	Female	Male
EGs	PBL with the CAIM for the hands-on STEAM activity	199	97	102
CGs	PBL strategy only for the hands-on STEAM activity	167	75	92
Total		366	172	194

3.2. Procedure

This study adopted a quasi-experimental research method to explore junior high school students' STEAM knowledge, creativity, and hands-on performance using different teaching strategies for a hands-on STEAM activity. As shown in Figure 1, the research was conducted over 10 weeks, in which the EGs adopted PBL with the CAIM, and the CGs applied the PBL strategy only. The project started in Week 2 and ended in Week 9, consisting of three learning stages, including a hands-on activity to build an electric boat. The research was conducted as follows:

(1) Weeks 1: The pre-test to evaluate the students' STEAM knowledge and creativity (60 min).
(2) Weeks 2 to 3: Learning Stage 1 (STEAM basic teaching): The students learned about the physical and mathematical knowledge required to build an electric boat, as well as the design principles of electric boats. Students also familiarized themselves with the electronic components related to Arduino, including LED, motors, switches, Bluetooth controllers, and electromechanical expansion boards (2 weeks, 180 min, 90 min each).
(3) Weeks 4 to 5: Learning Stage 2 (STEAM advanced teaching): The students learned how to analyze, conceptualize, and think about the ways to design an electric boat and proposed a design plan (2 weeks, 180 min, 90 min each).
(4) Weeks 6 to 9: Learning Stage 3 (STEAM project implementation): The students designed and built their electric boats through the generation of thematic creative ideas, appearance design, and assembly of hardware, as well as testing and modification. Finally, a presentation of the students' finished products was held in Week 9 (4 weeks, 360 min, 90 min each).
(5) Week 10: The post-test to evaluate the students' STEAM knowledge and creativity (90 min).

3.3. Development of the Learning Activity

The hands-on STEAM activity developed in this study was implemented using the PBL teaching strategy, which emphasizes continuous discussion, knowledge iteration, and integration with real-world problems and is therefore well suited to the hands-on design curriculum. The design process also helped the students consolidate their knowledge and promote teamwork. This course involved building an electric boat, as shown in Table 3.

Figure 2 illustrates the teaching flow of this study, and the contents are listed as follows. The first stage of this study was an introduction to scientific principles using the fundamental knowledge of STEAM to facilitate the students' understanding of scientific principles, design, and electronic components for an electric boat through cross-disciplinary STEAM knowledge. The second stage included advanced STEAM knowledge and boat design. It began with teaching circuit design and programing principles for the construction of Arduino electric boats. The teachers used ArduBlock and Arduino (IDE) to teach programing, followed by explaining the structures and design concepts of boats with the introduction of commonly seen boats in daily life. The students also had the opportunity to draw design sketches of their electric boats. In the third stage, the hands-on STEAM project was the core of the whole course, with electric boat creation as the theme of the project. The students solved problems in the boat-creation process and, finally, finished their final products. The students not only learned the theories but also related them with the things they saw in their daily life.

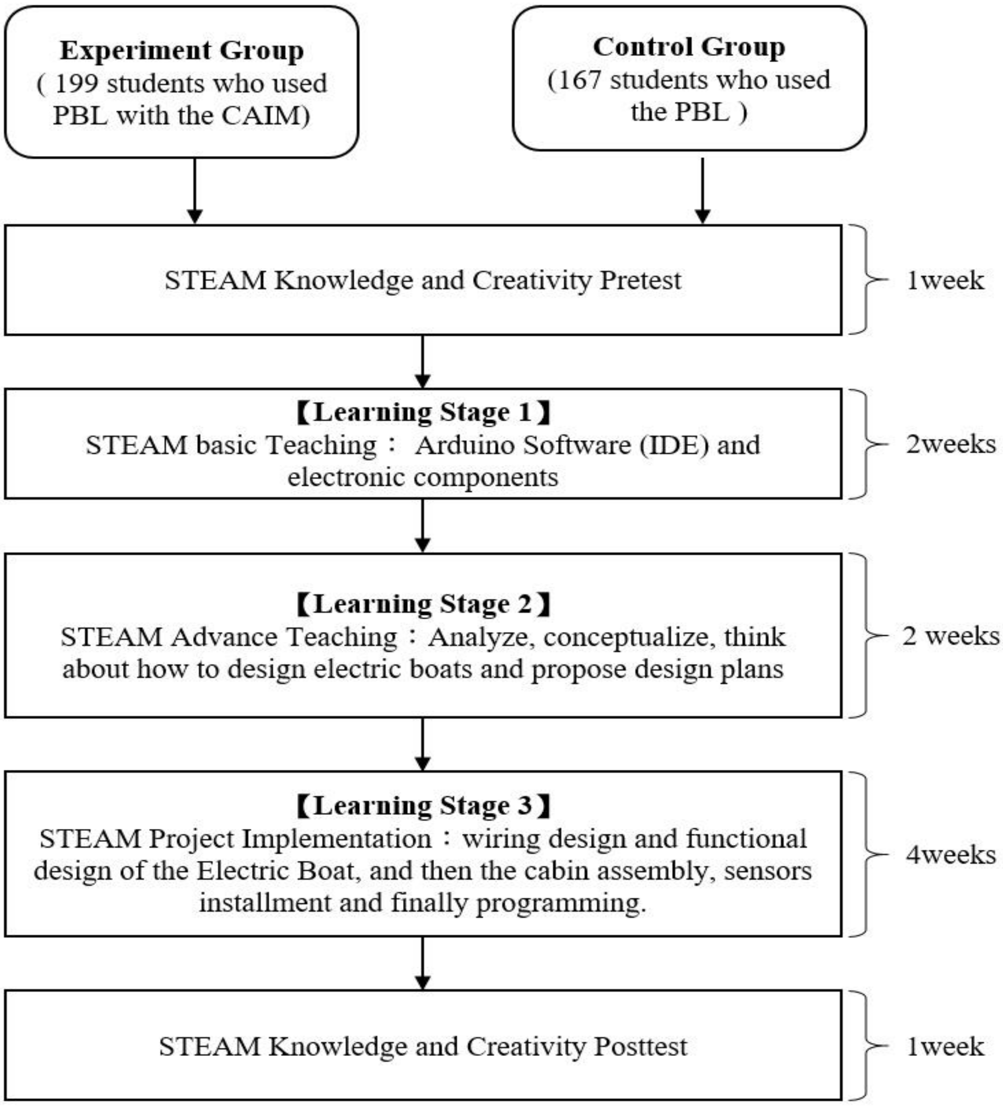

Figure 1. The experimental procedure.

Table 3. Contents and instructional design of the hands-on STEAM activity using the PBL teaching strategy.

Topics	Frequency and Course Objectives	Course Content	PBL Phases
Pre-test	Week 1: STEAM knowledge and creativity pre-test.		
Learning Stage 1: Scientific principles	Week 2: Introduction of scientific principles	Explain the principles of buoyancy, Newton's laws of motion, and electricity.	Definition and Planning, Projects Delivery, Renewal
	Week 3: Introduction of electric boat components and design	Learn about Arduino electronic components. Draft design for an electric boat.	Renewal, Dissolution

Table 3. *Cont.*

Topics	Frequency and Course Objectives	Course Content	PBL Phases
Learning Stage 2: Electric boat design principles	Week 4: Explanation of Arduino IDE and programing	Explain the construction of Arduino electric boats, including programing and circuitry.	Initiation
	Week 5: Explanation of the design principles of boats	Explain the design principles of boats. Introduce the three different types of boats. Draw a design sketch of an electric boat.	Definition and Planning, Projects Delivery, Renewal
Learning Stage 3: Electric boat implementation	Week 6: Electric boat design	Based on the students' designs, provide the students with parts packages for the electric boat.	Renewal, Dissolution
	Week 7: Electric boat design and implementation	Students work on their electric boat and record problems during the process.	Initiation
	Week 8: Electric boat design and implementation	Students work on their electric boat and solve problems during the process.	Definition and Planning, Projects Delivery, Renewal
	Week 9: Electric boat design and implementation	Students present their finished electric boats.	Renewal, Dissolution
Post-test	Week 10: STEAM knowledge and creativity post-test.		

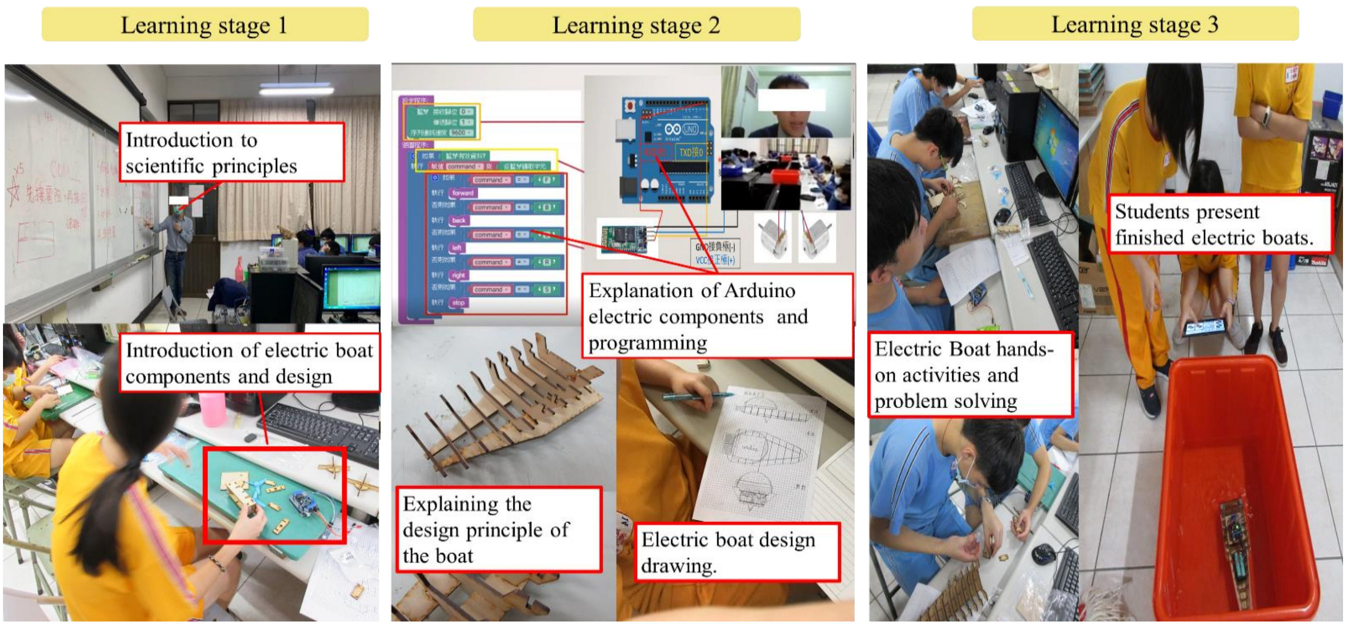

Figure 2. Project implementation.

Figure 3 shows the knowledge framework of this study. The knowledge domains included factual, normative, and value-based knowledge. By extracting the knowledge nodes from the specific knowledge domains of STEAM and analyzing and deconstructing the contents of the boat-making course in this study, the links between individual disciplines of STEAM were obtained. The curriculum design for this study was based on STEAM teaching and learning, which emphasizes the integration of knowledge aspects of various subjects and the linkage between different knowledge points of STEAM. The students were able to investigate and solve problems from multiple perspectives; it was, therefore, very suitable for use in the hands-on design curriculum. The design process also helped the students integrate their acquired knowledge and promoted teamwork.

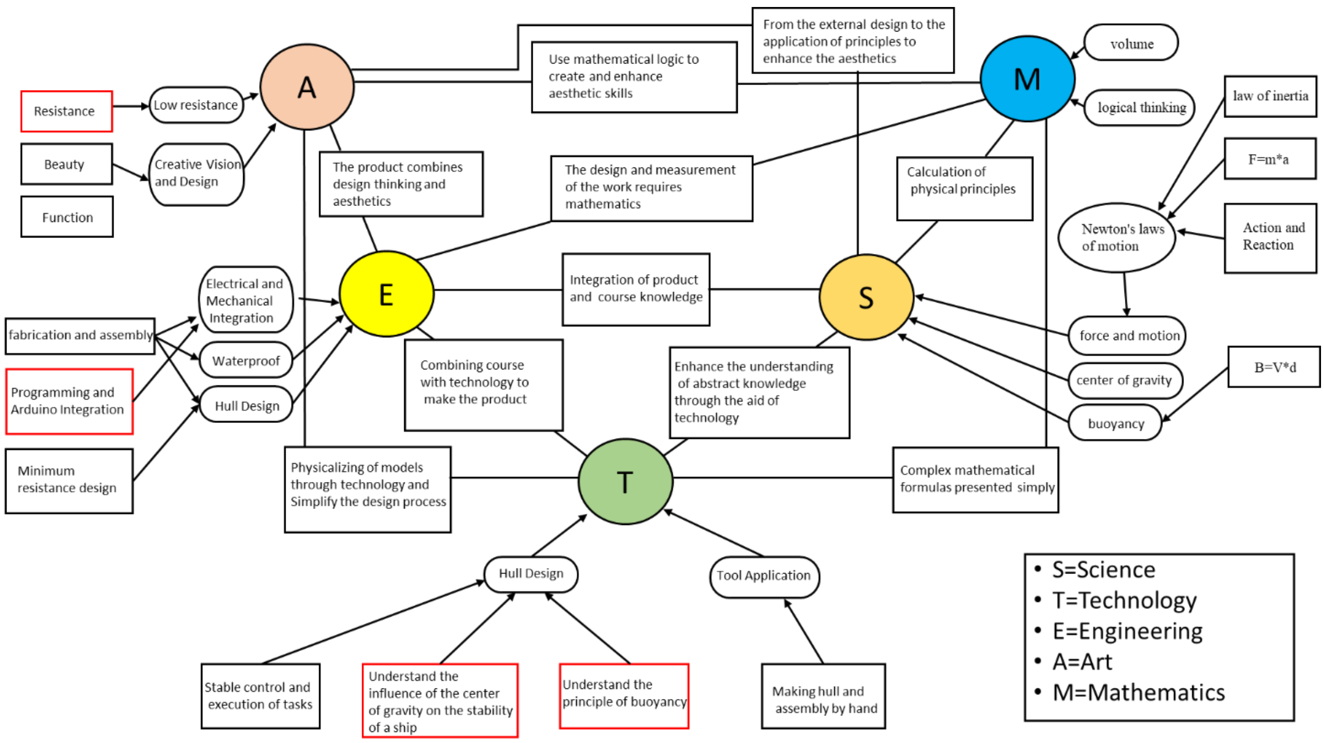

Figure 3. The STEAM knowledge framework.

In this study, the PBL phases (i.e., initiation, definition and planning, projects delivery, renewal, and dissolution) were used in the teaching structures in both the EGs and the CGs. Each phase of PBL was further divided into two parts: teacher instruction and student acquisition. The students worked in groups to explore, discuss, design, and execute the hands-on activity, while the teachers acted as facilitators to provide support and guidance. In addition, the CAIM was incorporated into individual phases of PBL for the EGs. In the first phase (initiation), the students explored and defined the problem, so "example of habit" was chosen. The second phase (definition and planning) aimed at provoking the students' thoughts by their presentation of problems, and therefore, "provocative questioning" was used. In the third phase (projects delivery), the students discussed their problems and collected information, so "skills of search" was used in this phase. In the fourth phase (renewal), the teachers acted as facilitators in the students' discussions, giving them insights to overcome their blind spots, and therefore, "example of change" was chosen. In the final phase (dissolution), the students presented their finished products, and the teachers gave feedback and suggestions to the students based on their presentations, so "evaluate situations" was used. An explanation of the CAIM and project implementation is shown in Figure 4. The overall instructional composition was based on the PBL phases, and each phase was further divided into two parts—teachers' instruction and students' acquisition—which were in accordance with the CAIM (i.e., example of habit, provocative questioning, skills of search, example of change, evaluate situations). In order to promote overall differentiation, the study employed two experienced teachers who were specialized in junior high school science and technology to discuss and amend the evaluation chart, with the aim of suitability for Grade 9 students, and both achieved expert validity and content validity.

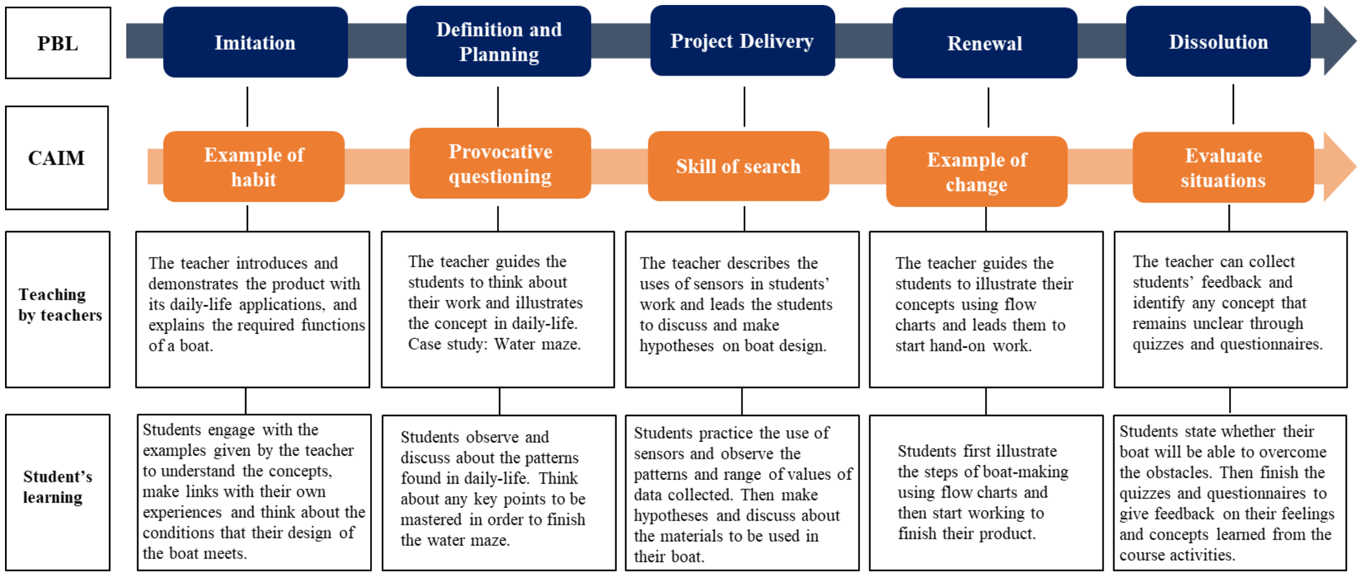

Figure 4. Teaching strategy of PBL with the CAIM for the learning activity.

3.4. Measurement Tools

3.4.1. STEAM Knowledge Examination Paper

This study applied a self-made tool called the STEAM Knowledge Examination Paper (STEAM KEP), with the primary purpose of assessing the students' understanding of the overall curriculum content knowledge, including Arduino (IDE) electronic components and scientific principles, together with the contents covered in science, technology, engineering, and mathematics. The questions were reviewed by an information technology teacher and a science and technology teacher, both of whom had many years of teaching experience, and hence, the STEAM KEP achieved content validity. The STEAM KEP was revised after receiving the experts' opinions. It had 20 questions, and each question was worth 5 points for a total of 100 points. The analysis of covariance (ANCOVA) was conducted for the analysis of the STEAM KEP in order to analyze the students' learning performance in relation to different teaching strategies.

3.4.2. Hands-On Performance

In Learning Stage 3, the students were required to finish their electric boats and demonstrate their performance in terms of creativity and hands-on design. This study used the CPAM to evaluate the students' hands-on performance [43]. The CPAM includes three subscales with nine indicators (see Table 4), which have been cited many times in previous studies and used in evaluations of students' hands-on performance [12,13]. The hands-on skills assessment was divided into three major dimensions with nine subscales, each of which was scored from 1 to 5 for a total score of 45. The scores were marked by the researcher and a science and technology teacher. Finally, the mean of two scores was an indicator of the students' hands-on performance. The two scorers observed the students' products together and discussed the students' performance before marking in order to avoid bias. Table 4 lists the scorer reliability examined by Cohen Kappa, which was between 0.65 and 0.82, showing that the two scorers had high consensus regarding the work evaluation [45]. For the analysis of hands-on performance, a *t*-test was conducted to analyze the students' hands-on performance (i.e., novelty, resolution, and elaboration and synthesis) in relation to the different teaching strategies.

Table 4. Scoring scales and evaluation criteria of the CPAM and scorer reliability.

Subscales	Indicators	Evaluation Criteria	Scorer Reliability
Novelty	Original	Whether the product is original. The extent of observation, duplication, and adaptation (e.g., changes in the hull, etc.).	0.82 ***
	Surprising	Whether the product is surprising (e.g., additional functions).	0.70 ***
Resolution	Valuable	Whether the design has the potential for continuous refinement and improvement.	0.75 ***
	Logical	Whether the design is logical (compared with the others or in terms of the rationality of the design with the components used).	0.67 ***
	Useful	Whether more electronic components are used or whether other kits altering the boat's functions are incorporated.	0.65 ***
	Understandable	Whether the product's design is understandable (with a clearly known rationale).	0.70 ***
Elaboration and Synthesis	Organic	Whether the boat can function properly (usable, with occasional pauses for repair, and quality of the ship's control).	0.79 ***
	Elegant	Elegance of the boat (in terms of the accuracy of the installation of components and the precision of the design).	0.72 ***
	Well crafted	Whether the appearance of the boat is beautiful and well crafted.	0.78 ***

Note: *** $p < 0.001$.

3.4.3. Creativity Scale

Williams [23] developed the Creativity Assessment Packet (CAP) in 1972, which can be used as an assessment tool for creativity. This study adopted the modified Chinese version of the CAP by Lin and Wang [46] as the assessment tool. The CAP is divided into three parts: "Test of Divergent Thinking", "Test of Divergent Feeling", and "The Williams Scale". The 3-point scale has 50 questions: 3 points for a perfect match, 2 points for a partial match, and 1 point for a total mismatch, for a maximum score of 150 points. The students were tested on four creative attributes: Risk taking, Curiosity, Imagination, and Complexity. The higher the students' scores, the higher the quality of their work. For the analysis of the creativity scale, ANCOVA was conducted to analyze the students' creativity in relation to the different teaching strategies.

4. Results

4.1. Influence of the Different Teaching Strategies on the Students' STEAM Knowledge

The STEAM KEP was used in the first week pre-test and the last week post-test, and it was used to measure students' STEAM Knowledge. Table 5 lists the statistical data for the students' STEAM knowledge performance. The scores of the post-test for both groups were higher than the scores of the pre-test, which showed that the course content designed in this study was helpful in enhancing the students' STEAM knowledge. Moreover, ANCOVA was used to compare the differences between the two groups. The homogeneity of regression ($F = 0.93$, $p = 0.34 > 0.05$) showed that the use of ANCOVA was appropriate. The results of ANCOVA demonstrated that the EGs achieved significantly better scores ($F = 14.60$, $p < 0.05$). In addition, the η^2 value was provided as a substitute for effect size ($\eta^2 = 0.02$) ($0.06 \geq \eta^2 > 0.01$, small effect) [45]. Based on the statistical data, it was deduced that there was a significant enhancement in the students' STEAM knowledge through continuous improvement by trial and error during the hands-on activity. This was in line with the results proposed by Kuo et al. [31]. After further posteriori comparison, the EGs performed better than the CGs in terms of STEAM knowledge ($MD(I–J) = 3.04$; $p = 0.007$).

Table 5. Summary of the statistical data on the students' STEAM knowledge.

Groups	Pre-Test			Post-Test		ANCOVA		
	N	Mean	SD	Mean	SD	Adjusted Mean	*F*	*p*	η^2
EGs	199	53.42	9.67	62.44	11.85	62.19 [a]	7.25 **	0.007	0.02
CGs	167	52.28	9.69	58.86	11.40	57.52 [a]			

Note: [a] The pre-test score was used as the covariate = 52.90; ** $p < 0.05$.

4.2. Influence of Different Teaching Strategies on Creativity

The CAP was used in the first week pre-test and the last week post-test, and it was used to measure students' creativity. Table 6 lists the statistics of the students' creativity performance. The scores of the post-test were better than those of the pre-test for both the EGs and the CGs, indicating that the strategy of PBL was helpful in improving creativity. In addition, ANCOVA was used to compare the differences between the two groups. The homogeneity of regression ($F = 1.16$, $p = 0.28 > 0.05$) indicated that the use of ANCOVA was appropriate. Moreover, the results of ANCOVA demonstrated that the EGs achieved significantly better scores than the CGs ($F = 26.56$, $p < 0.001$). In addition, the η^2 value was provided as a substitute for effect size ($\eta^2 = 0.068$) ($0.06 < \eta^2 < 0.138$, medium effect) [44]. After further posteriori comparison, the EGs performed better than the CGs in terms of creativity ($MD(I–J) = 6.04$; $p < 0.001$). One possible reason for this result was that PBL with the CAIM was used for the EGs, such that the students had more opportunities for independent learning and stimulating different thinking. [25]. In order to understand the effects of different teaching modes on each sub-dimension of creativity (i.e., Risk taking, Curiosity, Imagination, and Complexity), ANCOVA was conducted for each sub-dimension in this study, as shown in Table 7. The results showed that using PBL with the CAIM helped the students engage in the learning contexts, and their performance in "Curiosity" and "Complexity" improved. For example, the students' creativity was enhanced by providing them with extra choices for materials and the appearance of the boats and by challenging them to solve different types of problems. These findings were in line with those from the research conducted by Adriyawati et al. [36].

Table 6. Summary of the statistical data on the students' creativity.

Groups	Pre-Test			Post-Test		ANCOVA			
	N	Mean	SD	Mean	SD	Adjusted Mean	*F*	*p*	η^2
EGs	199	107.43	11.85	110.68	12.65	111.52 [a]	26.56 ***	<0.001	0.068
CGs	167	109.98	12.32	106.48	15.80	105.48 [a]			

Note: [a] The pre-test score was used as the covariate = 108.59; *** $p < 0.001$.

Table 7. Summary of the posteriori comparison of various creativity indicators.

	Source of Variation	Sum of Squares	Degree of Freedom	Mean Sum of Squares	*F*	*p*	η^2
Risk taking	Group	2.641	1	2.61	0.38	0.539	
	Deviation	2504.538	363	6.9			
Curiosity	Group	52.16	1	52.16	5.32 **	0.022	0.014
	Deviation	3560.78	363	9.81			
Imagination	Group	26.67	1	26.67	2.45	0.118	
	Deviation	3952.86	363	10.89			
Complexity	Group	92.54	1	92.54	9.83 **	0.002	0.026
	Deviation	3415.85	363	9.41			

Note: ** $p < 0.05$

4.3. Influence of Different Teaching Strategies on Hands-On Performance

In Learning Stage 3, CPAM was used to evaluate the performance of the product. Table 8 shows the results of the students' hands-on performance. Each group of students built an electric boat. The ANOVA results demonstrated that the EGs achieved significantly better scores ($F = 11.38$ ***, $p < 0.001$). In addition, the *Cohen's d* = 0.65 value was provided as a substitute for effect size ($0.2 < d < 0.8$, medium effect) [45]. From various indicators, it was found that there were significant differences between the EGs and the CGs. According to the results of the individual items, the students in the EGs performed remarkably better in terms of "Original" and "Surprising", indicating that the teaching strategy used stimulated the students to think in different ways [16,25]. Moreover, the students used various materials to expand the structures and functions of their electric boats during the learning process using the CAIM. As a result, the students' products were improved in terms of "Valuable", "Useful", and "Elegant", without defective or unfinished work. In addition, the students were able to switch to other possible methods when they encountered difficulties. These findings were in line with those in the research works of Lin et al. [30] and Wells et al. [13].

Table 8. Statistical data on the students' hands-on performance.

Indicators	Group	Mean	SD	*F*	*p*	*Cohen's d*
Total Score	EGs	30.04	3.70	11.38 ***	0.001	0.65
	CGs	27.41	4.38			
1. Novelty						
1.1 Original	EGs	3.87	0.80	8.91 **	0.004	0.57
	CGs	2.69	0.57			
1.2 Surprising	EGs	4.02	0.72	4.82 **	0.030	0.42
	CGs	2.91	0.71			
2. Resolution						
2.1 Valuable	EGs	3.85	0.68	7.26 ***	0.008	0.52
	CGs	1.97	0.57			
2.2 Logical	EGs	0.28	0.52	2.01	0.150	
	CGs	1.86	0.50			
2.3 Useful	EGs	3.93	0.44	5.58 **	0.020	0.45
	CGs	3.35	0.37			
2.4 Understandable	EGs	3.96	0.43	3.43	0.067	
	CGs	3.22	0.50			
3. Elaboration and Synthesis						
3.1 Organic	EGs	4.04	0.41	3.68	0.58	
	CGs	3.95	0.28			
3.2 Elegant	EGs	4.06	0.42	4.26 **	0.041	0.40
	CGs	3.95	0.28			
3.3 Well crafted	EGs	4.45	0.42	1.67	0.20	
	CGs	3.40	0.64			

Note: ** $p < 0.05$; *** $p < 0.001$.

5. Discussion

This study aimed to develop a hands-on STEAM activity appropriate for Grade 9 students, with the theme of electric boat making, and investigate the influence of the different teaching strategies (i.e., PBL with the CAIM vs. PBL only) on the students' STEAM knowledge, creativity, and hands-on performance. In accordance with the study, the results were discussed as follows.

5.1. Design of the Hands-On STEAM Activity

This study applied PBL with the CAIM to develop a hands-on STEAM activity, and the learning contents covered the knowledge and abilities of science, technology, engineering, the arts, and mathematics. According to the on-site observations, the combination of lecturing and hands-on learning facilitated the students' understanding of the concepts of an electric boat and provided them with the opportunity to build an electric boat with their own hands using Arduino hardware, a coding program, and a wireless Bluetooth device. The project was divided into three stages—(1) STEAM basic knowledge: introduction of scientific principles; (2) STEAM advanced knowledge: introduction of design principles of electric boats; and (3) electric boat project implementation: wiring design and functional design of electric boats—in order for the students to gradually acquire and accumulate knowledge, concepts, and skills. At the same time, the hands-on activity manifested the idea of "learning by doing" [38]. The students in the EGs and CGs both demonstrated involvement in the hands-on activity. This proved that the hands-on STEAM project with the theme of electric boat making was attractive to these Grade 9 students.

5.2. Effectiveness of the Different Teaching Strategies (i.e., PBL with the CAIM vs. PBL Only) on the Students' STEAM Knowledge, Creativity, and Hands-On Performance

5.2.1. Effects of the Different Teaching Strategies on the Students' STEAM Knowledge

This study used a hands-on STEAM activity with PBL pedagogy to help the students turn their classroom knowledge into hands-on products, with the expectation of enhancing the students' familiarity and application of their knowledge by integrating different disciplines. Based on the statistical analysis of STEAM knowledge, it was found that students in the EGs and the CGs progressed significantly according to the results of the pre-test and post-test. Based on the ANCOVA results, students in the EGs performed significantly better than those in the CGs in terms of STEAM knowledge. The results of the study showed that the EG students who used PBL with the CAIM improved their STEAM knowledge more than the CG students did, indicating that the teaching model used in the EGs effectively enhanced the students' application and understanding of STEAM knowledge. Based on these results, it was assumed that there was a significant enhancement in the students' STEAM knowledge through continuous improvement by trial and error during the hands-on activity. This prediction was in line with the results proposed by Kuo et al. [31].

5.2.2. Effects of the Different Teaching Strategies on the Students' Creativity

Using the PBL teaching strategy, the teachers presented the topic of the teaching activity (i.e., building an electric boat) and supplemented it with news, photos, and real models to help the students develop a connection and concept of an electric boat. Through the PBL teaching strategy, the students' learning outcomes were enhanced by discussing and sharing knowledge with each other during the hands-on activity. Based on the ANCOVA results, students in the EGs performed significantly better than those in the CGs regarding creativity. Therefore, the study reasonably assumed that because of the application of PBL with the CAIM, students in the EGs were positively affected in their learning motivation and that students had more opportunities for independent learning and thinking from different perspectives [16,25]. The researcher found in the teaching setting that students in the EGs were able to apply the inspirations gained during discussions. For example, they understood the effects of the weight of different wrapping materials on their supporting strength and the appearance of the electric boats through exploration. Another example was that through modification, students were able to expand the functions and structures of their electric boats by changing the materials used. Therefore, their products were better developed with higher value. These findings also showed that students' performance in "Curiosity" and "Complexity" was improved by using PBL with the CAIM. For example, students' creativity was enhanced by providing them with extra choices of materials and appearances of the boats and challenging them to solve different types of problems. These findings were in line with those from the research conducted by Adriyawati et al. [36]. According to the design drafts drawn by the students, the researcher also found that those in the CGs were mostly monotonous. Although the dimensions and the materials used were clearly stated, less creativity was demonstrated, and no extra modifications were included.

5.2.3. Effects of the Different Teaching Strategies on the Students' Hands-On Performance

The researcher observed that students applied the physical principles and the structure of the electronic components learned in the lessons to match the electronic components of different structures and uses when building their electric boats. In addition, when observing the structure of their boat, students were able to understand the configuration and design of different parts of their electric boat clearly, and their efforts were reflected in their design drawings and final products (as shown in Figure 5). Based on the *t*-test results, students in the EGs performed significantly better than those in the CGs in terms of hands-on performance. Therefore, through PBL with the CAIM, students in the EGs were able to make products of higher quality, observe the structures of different types of boats, and have more choices of materials when designing their own boats. According to the results of the individual items, students in the EGs performed remarkably better in terms of "Original" and "Surprising", indicating that their overall performance in "Novelty" was enhanced through using the CAIM in their learning process. These findings showed that creative abilities were essential, which was in line with the study of Adriyawati et al. [36]. Moreover, students in the EGs performed remarkably better in terms of "Valuable", "Useful", and "Elegant", showing that they were able to switch to other appropriate methods to avoid making defective products or failing to complete their products in the boat-making process. These findings were similar to those in the research works of Lin et al. [30] and Wells et al. [13]. In order to improve the function of their boat, students added different electronic components and materials to the boat. For example, they added more motors to solve the problem of insufficient power due to increased weight. In order to help the boat sail faster on the water, they used aluminum cans and other materials to help the boat move easier on the water's surface. In contrast, even though students in the CGs were able to sketch the design of the electric boat well and prepare the materials required with the help of PBL, they did not have many new discussions during the process and so their products were rather monotonous and homogeneous.

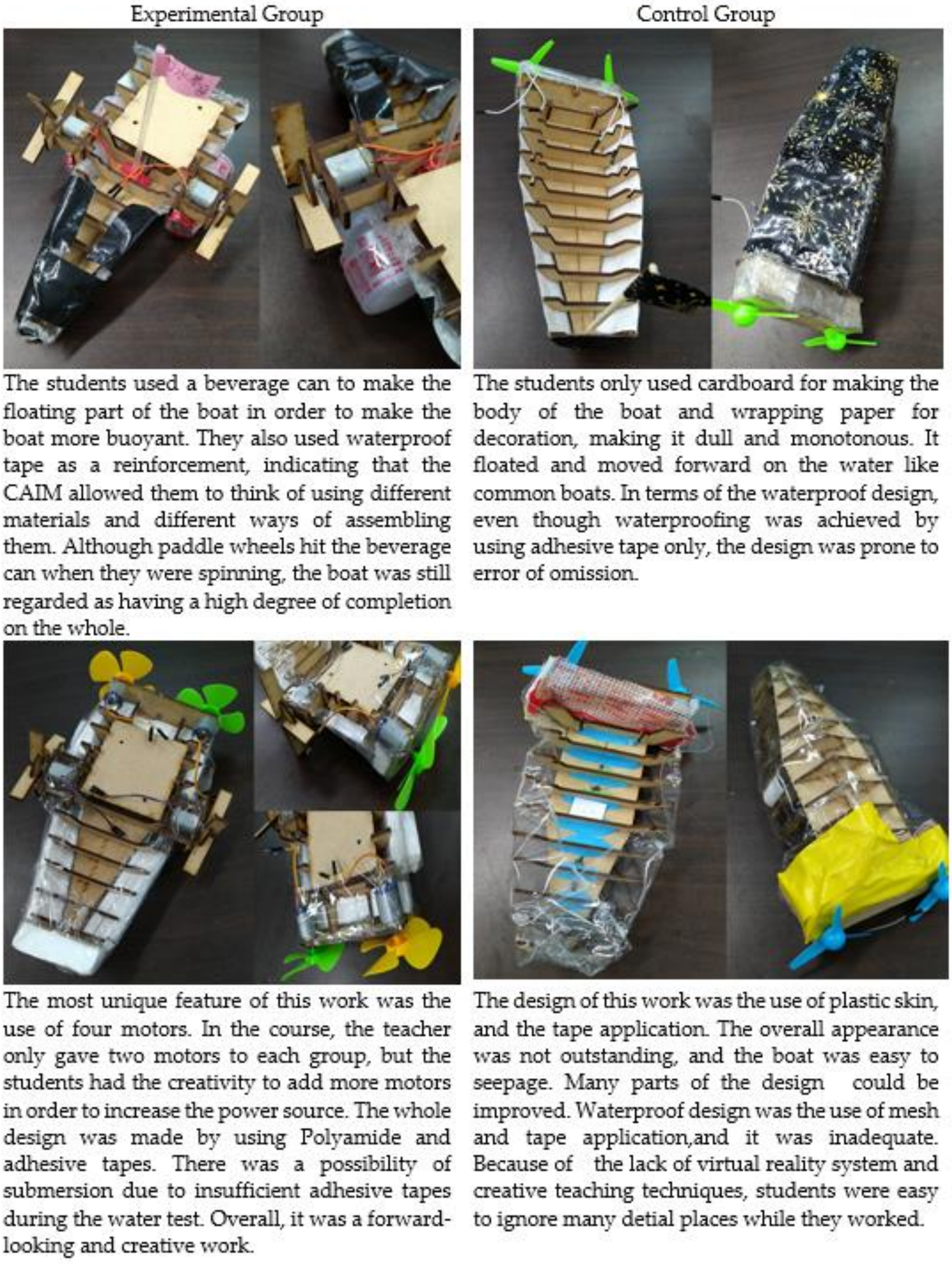

Figure 5. Comparison between the electric boats built by an experimental group and a control group.

6. Conclusions

In the research on how STEAM education can change the development of education in the future, this study carried out two parts of research: the first part is the researcher design of a hands-on STEAM activity that incorporated PBL with the CAIM, and the curriculum provides students with the knowledge required for STEAM education; the second part is the research on the application of effectiveness of the different teaching strategies on the students' STEAM knowledge, creativity, and hands-on performance. The research results show that electric boat making was chosen as the core of the hands-on STEAM activity in this study. This activity effectively helped the students apply their knowledge acquired in the lessons. The activity not only enhanced the students' acceptance of knowledge but also strengthened their interest in learning and learning outcomes through PBL, including teamwork, discussion, and reflection. The students' acquisition of STEAM concepts cultivated their creativity, which could ultimately influence their choice of future careers, and this finding was meaningful, as it achieved one of the SDG 4′s objectives.

According to the results, using PBL pedagogy, students effectively learned and constructed new knowledge through group discussions when they faced unknown knowledge. Interactions and discussions between the group members was also useful in knowledge construction. The CAIM fostered the students' creativity, which was effectively demonstrated in their finished products. It also guided students to come up with a variety of outcomes in their discussions. This study also provides a pedagogy manuscript for instructors who want to teach interdisciplinary knowledge and hands-on activities. Finally, although this study proved the feasibility of the hands-on STEAM activity, there are some recommendations for future studies: (a) The target population of this study was 9th Grade students, who were less familiar with handicraft and equipment operation. Future research might consider strengthening their knowledge and skills to help students and let students have more choices and techniques in creating finished products; (b) The PBL CAIM teaching strategy could be applied to practical and creativity thinking courses. In the future research, there are more learning influences (e.g., motivation, self-efficacy, etc.) that could be explored.

Some research limitations must be noted: (a) The project was conducted in groups, each consisting of six to seven students, and the collective project task was completed with only one point of hands-on performance per group, which made it difficult to avoid the free-rider effect; (b) Since this study was conducted on a class basis, it was not possible to split the classes evenly for the experimental groups and the control groups, so the number of students in each group varied. (c) Based on the previous research works, there were no regulations of the application of CAIM. Hence, the researchers used expert interviews to find out the suitable teaching strategies. In the future studies, the researchers could try to find out diversified teaching strategies.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of National Taiwan Normal University (REC Number: 202008HS005 and Approval Date: 29 September 2020) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: For ethical reasons and restrictions, the datasets used and analyzed for the paper are not publicly available. However, any inquiries concerning the materials are welcomed.

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