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Effect of Using TRIZ Creative Learning to Build a Pneumatic Propeller Ship while Applying STEM Knowledge*

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This study aims to explore the effects of the Theory of Inventive Problem Solving (TRIZ) creative learning method to build the pneumatic propeller ship while applying STEM (science, technology, engineering, and mathematics) knowledge among Taiwanese female high school students. The subjects were 70 female students from a high school in Pingtung, Taiwan. An online platform was created and served as the TRIZ creative learning environment for the pneumatic propeller ship project. The students were provided with opportunities to discuss, share, and integrate their knowledge. Questionnaires and focus group interviews were conducted for data collection and analysis. The findings of this study revealed that (1) the STEM & TRIZ integrated instruction model can systematically promote STEM knowledge integration and application; (2) applying TRIZ creative learning to STEM knowledge show positively influences on students' learning; (3) the STEM & TRIZ integrated instruction model can enhance students' learning attitudes and interests; (4) the STEM & TRIZ integrated instruction model can enhance students' creativity and efficiency and cultivate students' innovative skills; and (5) applying TRIZ creative learning to STEM knowledge positively influences the students' creative learning.

Keywords: TRIZ creative learning; STEM knowledge; female high school students

1. Introduction

1.1 Research background and purpose

The STEM (science, technology, engineering, and mathematics) integrated courses present new educational issues. Instructors design the STEM courses to enhance students' problem-solving, decision-making, and study skills by requiring students to complete independent learning activities over a period of time and then present their work [6]. Besides cross-field integration, STEM courses emphasize and promote practice in real-world situations. In this way, learners can review and incorporate the comprehension and application of science, technology, engineering and mathematics at any time. The educational courses in the UK, South Africa, Sweden and New Zealand value the practice of problem solving [15], while in Taiwan, in the curricula of grades 1 through 9, the percentage of Do It Yourself (DIY) instruction sections is quite low (2.8%) in comparison. In the UK, only 8% of courses incorporate DIY instruction [19]. The use of these techniques will influence an individuals' ability to solve the problems on their own.

The "White Paper on Creative Education" presented by Taiwan's Ministry of Education in 2007 suggests that to increase the degree of creativity among the Taiwanese population, it is necessary to enhance people's creative potential by reinforcing and enhancing their problem-solving competences, allowing them to develop multiple skills and promoting rich self-value [10]. However, it seems that Taiwan does not value the cultivation of technology competence [1]. Much of the literature related to creativity introduces and focuses on skills, such as brainstorming techniques and attribute listing techniques, that emphasize observing and analyzing the characteristics of things or problems and presenting solutions or improvements. However, the literature

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does not present innovative examples of the application of creative thinking to professional knowledge in various subject areas. Thus, even with a sufficient thinking capacity, students lack the effective strategies needed to solve problems.

Therefore, PBL (Project-Based Learning) provide a sound learning model for the integrated learning of engineering and technology [17] and effectively enhance STEM knowledge learning. The Theory of Inventive Problem Solving (TRIZ) converts the contradiction and conflict of systematic technologies into benefits; it induces effective ways to solve problems and reduces the time required for the research and development to promote creativity among students [3]. Thus, this study employs PBL to recreate the pneumatic propeller ship design competition and uses TRIZ to promote diverse, creative teaching and learning techniques that support STEM integrated knowledge learning by cultivating the problem-solving abilities of the students.

As a result, this study aims to explore the effect of applying the TRIZ creative learning to STEM knowledge in female high school students and to develop an integrated instruction model of STEM and the TRIZ based on online interactions between the two learning techniques. The purposes of this study are:

(1) to develop a STEM & TRIZ integrated instruction model;
(2) to explore the effectiveness of a STEM & TRIZ integrated instruction model on student learning;
(3) to understand students' attitudes toward the STEM &TRIZ integrated instruction model;
(4) to analyze the effectiveness of the STEM & TRIZ integrated instruction model on enhancing student creativity.

2. Literature review

2.1 STEM integrated education model

STEM instruction refers to a teaching model that combines science exploration, technology, engineering design, and mathematical analysis. In this regard, science emphasizes the exploration of nature and natural events; engineering focuses on designing necessary tools through scientific findings; technology emphasizes producing the actual products based on the engineering design; and mathematics focuses on analyzing and evaluating statistics of integrating acquired scientific knowledge with science [9]. The integration includes curricula content, educational activities and educational policy. Thus, students acquire general knowledge, cultivate an interest in science technology and become actively involved in scientific studies.

The STEM integrated courses combine the concept and behavior of engineering with the curricula of science, technology and mathematics, and the courses are implemented in an engineering environment, providing students with a DIY experience, that is, real problem solving experiences [11]. Research findings related to STEM instruction are shown in Table 1.

Based on the above, the STEM integrated instruction model significantly enhances the students' communication and cooperation skills. Furthermore, after STEM instruction, students are better able to solve their own problems, and they have an increased interest in engineering technology. This study adopts the STEM instruction model and designs instruction activities based on the creative learning of science, technology, engineering and mathematics to increase student interest in learning and improve the effectiveness of learning.

2.2 TRIZ

2.2.1 Introduction of TRIZ

TRIZ is a Russian acronym for the Teoriya Resheniya Izobretatelskikh Zadatch. The English translation is the Theory of Inventive Problem Solving (TIPS), which means "problem-solving theory of innovation and invention." According to an analysis of the patent documents, the theory was developed by Genrish Squlovich Altshuller, a Russian

Table 1. Studies related to STEM integrated instruction

Authors	Related research conclusions
Olds, Patell, Yalvac, Kanter, and Goel (2004)	1. Approximately 90% of the students indicate that after participating in the courses, they understand previous lessons presented in the classrooms [13]. 2. Approximately 80% students indicate that after participating in the courses, they have better communication skills [13].
Zarske, Sullivan, Carlson, and Yowell (2004)	After STEM integrated instruction, elementary school students' post-test scores were significantly higher than their pre-test in three courses [8].
State Technology Report (2008)	1. After STEM instruction, grade 4 students' mathematics performance on NAEP increased by 4.2% from 2003 to 2007 [16]. 2. After STEM instruction, grade 8 students' mathematics performance on NAEP increased by 3.7% from 2003 to 2007 [16].

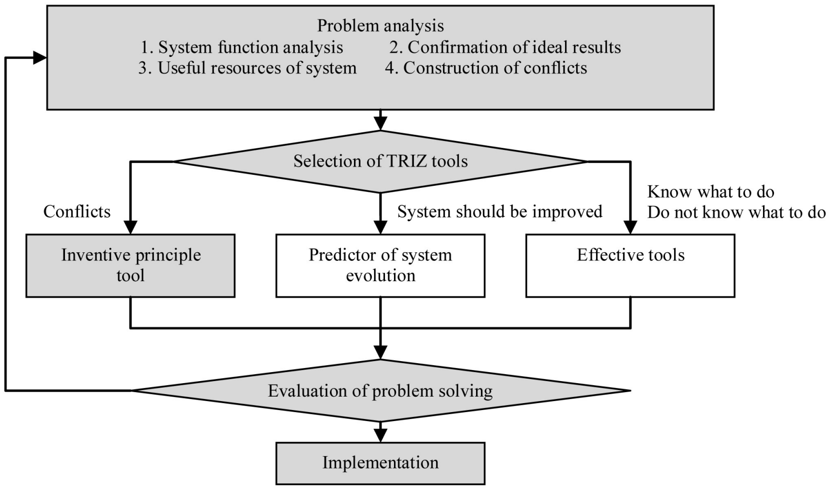


Fig. 1. The TRIZ problem-solving steps [14].

inventor and engineer, and his team [3]. After reading a great number of patents, Altshuller recognized a general pattern or model for problem solving in these independent patents and suggested that if the invention principles could be confirmed and reorganized, the principles could become guidelines for inventors and thus improve their invention process.

2.2.2 Problem-solving steps of TRIZ

When applying the TRIZ to solve creative problems, we started from problem analysis, which mainly included the confirmation of ideal results, conflicts, system function analysis and useful resources of the system. According to practical application, the function analysis can be divided into "technical system analysis" and 'technical process analysis." After confirmation of the ideal results, the problems were recorded in detail, and problem-solving tools based on attribute classification were identified. The problem-solving strategies were then evaluated [14]. The most common measure for problem solving was Pugh's concept selection method, as shown in Fig. 1. As 90% of the problems have been solved in other fields, the solutions generalized by the TRIZ can reduce the time for mistakes.

The major tools in the TRIZ can be categorized into the following:

(1) Inventive principle tool: Altshuller's 40 inventive principles that provide solutions to the 39 features of the contradictory matrix.
(2) Predictor of system evolution: the TRIZ provides 76 standard solutions, thus permitting the quick modeling of simple structures for substance-field analysis.
(3) Effective tool generation: the TRIZ is also used to provide effective tools to solve strong couplings and adequately convert the cases through highlighting the contradictory parameters.

Because the subjects of this study were female high school students, the researchers employed a more fundamental procedure of the TRIZ application. The procedures employed were as follows: 1) problem analysis, 2) selection and application of the TRIZ tools, 3) evaluation of problem solving, and 4) implementation for guiding students and stimulating their potential innovative creativity (Fig. 1).

2.2.3 TRIZ tasks in this study

"Three steps to solve innovative problems" referenced in the introduction of the TRIZ—TRIZ 40 Principles Design are treated as three stages of practice in this study, as shown in Fig. 2 [4]. These three stages guide the students so they can easily learn and incorporate the TRIZ, as shown below. During the instruction, teachers control the effectiveness of student learning as well as the project activity by implementing tasks in three stages, which properly guide and inspire the students and help them apply the STEM integrated knowledge in practice to enhance the creative potential and creative thinking abilities of the students.

2.3 Content of PBL instruction strategy and related studies

PBL is a systematic instruction that integrates the curricula of different subjects, as it allows students to pose questions and investigate various real-world issues. By combining instruction materials from various subjects, students have access to a widebreadth of knowledge. Through the in-depth study of a complicated issue and the active engagement in planned tasks, the students successfully acquire the

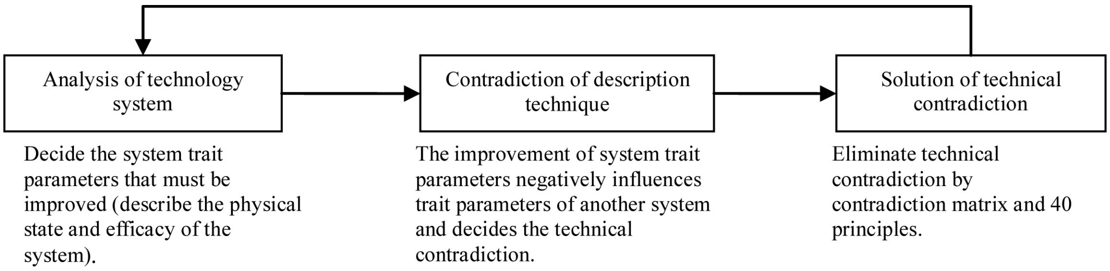


Fig. 2. Three steps to solve innovative problems, adopted from Altshuller, G. (1974) [4].

knowledge and skills necessary to solve the posed problem [12]. Thus, by conducting project studies, exploring related topics, designing and planning projects, gathering data, and presenting the final work product, project-based learning provides the students with highly complicated and realistic project-based learning [18].

In addition, PBL emphasizes that the problems explored by students must be real world/real life situations. As such, PBL provides the tools of the real community so that students can apply their learning to their own lives and, thus, enhance their motivation to learn. The characteristics of PBL are similar to those of situated learning theory in that PBL values the connections between learning and the environment and the application of knowledge. Moreover, it promotes dynamic learning and encourages teachers to allow the students to select their projects. Thus, learning becomes an intentional activity [7].

Through the implementation of PBL and the guidance of the instructor, students are able to share knowledge, discuss problems, explore issues, think creatively and thus construct their own knowledge and viewpoints. Meanwhile, the instructor adjusts the course and the learning activities according to the students' interactions and encourages the participation of the students to promote learning effectiveness.

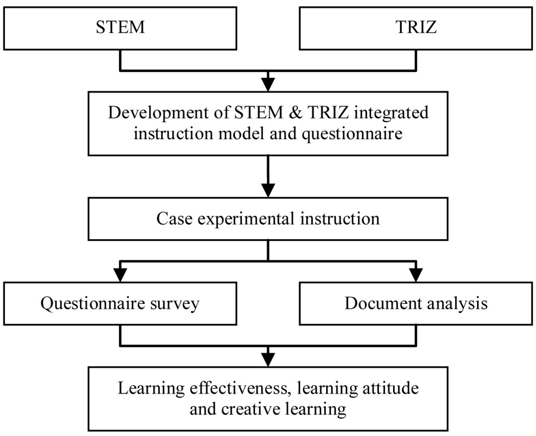


Fig. 3. Framework of research process.

3. Research method and implementation

Research method and process are shown in Fig. 3.

(1) Collect and analyze data related to the STEM instruction and the TRIZ through a literature review.
(2) Generalize and develop the STEM and TRIZ integration instruction model and the questionnaire of learning satisfaction.
(3) Carry out case experimental instruction according to the STEM and TRIZ integrated instruction model.
(4) Administer the questionnaire survey and analyze student learning records (discussion forums, chat rooms, and uploaded assignments) in the online learning platform.
(5) Probe into the influence of the STEM and TRIZ integrated instruction model on learning effectiveness, learning attitude and creative learning.

3.1 The STEM and TRIZ integrated instruction model

After the literature review of the STEM instruction and the TRIZ, this study develops the STEM and TRIZ integrated instruction model (Fig. 4). "Three steps to solve innovative problems" of the TRIZ are treated as tasks in three stages. Students accomplish three tasks, in order, using the STEM integrated knowledge to find the corresponding invention principles. Upon analogy, the STEM integrated knowledge is included. With the repetitive application of the integrated knowledge of science, technology, engineering, and mathematics, the study allows the students to solve problems, make decisions and practice, thus promoting the comprehension and application of science, technology, engineering and mathematics skills.

3.2 Core objective design of project activity

The task for this study, which is to build a pneumatic propeller ship, combined PBL and the TRIZ creative learning as the major instructional methods, while adhering to the STEM instructional guidelines in its integration of science, technology, engineering, and mathematics as the major instruc-

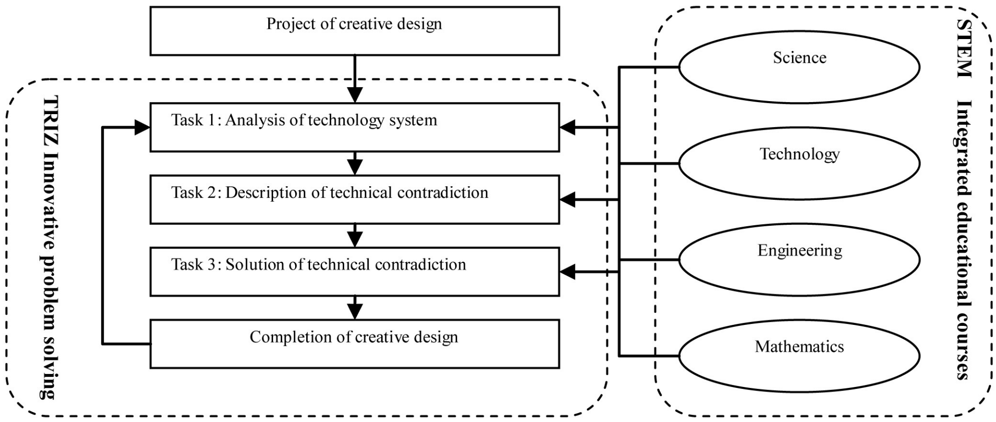


Fig. 4. STEM and TRIZ integrated instruction model.

tional core subjects (Table 2). Thus, the researchers were able to analyze the data from the online learning platform, which allowed the researchers to determine how the students used the TRIZ inventive tools to conduct systematic analyses, solve problems, and address contradictions as they worked to improve the outcomes of their projects through cooperative learning and knowledge sharing.

The PBL activity for this study lasted six weeks. Specific major learning objectives were identified for each week.

Week 1:

The fundamental courses include Introduction to PBL (3 hrs), Grouping and Instruction on the online learning platform (5 hrs), Instructions for building the pneumatic propeller ship (4 hrs), Building the pneumatic propeller sample ship (8 hrs), STEM knowledge instruction of the pneumatic propeller ship (8 hrs), and TRIZ instruction (12 hrs).

Week 2:

TRIZ—technology analysis system: Each group must record the manufacturing process of the sample ship, test its functions, and discuss issues based on the TRIZ Task 1 in the online learning platform. Through the application of STEM knowledge, group members should come to consensus on the parameters for improvements and then upload their decisions online.

Week 3:

TRIZ—describing the technical contradictions: Students adjust the parameters and decide on the technical contradictions based on the discussions and knowledge sharing from the TRIZ Task 1. Through the detailed description, students under-

Table 2. Design of instruction core objectives

Categories	Instruction core objectives	
Science (S)	1. Buoyancy 2. Hydrodynamics 3. Conservation of Energy 4. Function and power	5. Rotation and the moment 6. Inertia 7. Friction
Technology (T)	1. Ship structure 2. Hydrodynamics 3. Mechatronics control 4. System engineering 5. Ship design	6. Motor control 7. Advance of pneumatic propeller 8. Material selection 9. Manufacturing analysis 10. Manufacturing security
Engineering (E)	1. Problem solving 2. Creative thinking 3. Modeling design	4. Structure design 5. Drawing of blueprint
Mathematics (M)	1. Square measure 2. Volume 3. Buoyancy 4. Radius and diameter 5. Perimeter	6. Distance 7. Angle 8. Rotational speed 9. Wind velocity 10. Torque

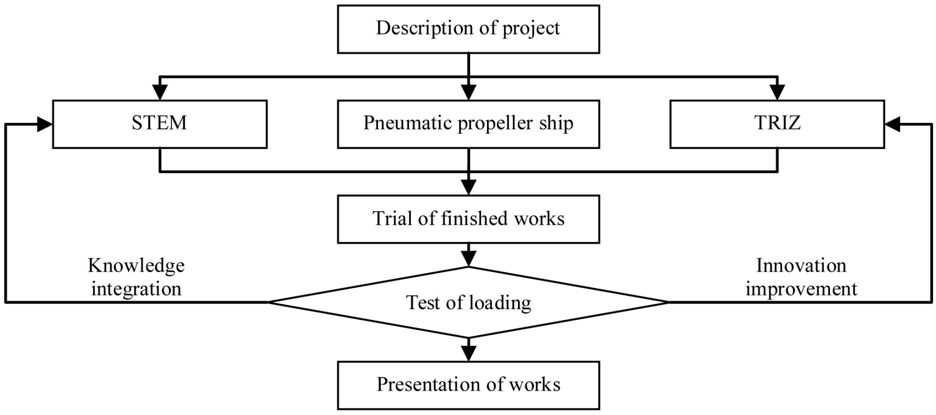


Fig. 5. Process of project activity.

stand the content of the STEM knowledge and upload their Week 3 assignments to the platform.

Week 4:

TRIZ—solving the technical contradictions: According to the results of Task 2, technical contradictions through group cooperative learning and online discussions, students identify the inventive theory by applying the contradictory matrix. Further, students combine the STEM knowledge to find the most suitable inventive theory for solving the technical contradictions and then upload them to the online platform.

Weeks 5 and 6:

Discussion and presentation: Combining the three tasks of TRIZ, students designed and built an innovative pneumatic propeller ship to reach its optimization. Students present their completed project for evaluation and sharing. Students discuss and exchange their learning experiences.

3.3 Project activity design and implementation process

The subjects who participated in the competition of the TRIZ creative design of a pneumatic propeller ship from a national female high school in Pingtung City. There were 18 groups registered that included 72 participants. Initially, the subjects were introduced to the research topic, the activity and the process. The activity was based on learning tasks. Each group searched for information on the topic, discussed it in an online forum and presented the related content, learning and results through an online learning platform. The activity lasted six weeks. Finally, the projects were presented and project briefings and efficacy competitions were held to award the prominent groups. There were opportunities to exchange experiences and share learning. The activity process is shown in Fig. 5.

3.4 Research tools

3.4.1 Online learning platform

This study constructs an interactive online learning platform for the STEM & TRIZ integrated instruction for student online discussion and researcher data collection. The main functions of the platform include question guiding, bulletin boards, chat rooms, forums, data uploading and downloading, online assistance, etc. Group members can freely share their discussions, experimental findings and problems they encounter during the project on the platform. The online assistant instructs the students at any time, and the process is recorded in the database of the online platform.

3.4.2 Questionnaire

After developing the questionnaire survey of instruction activity, two scholars perform an expert validity check. Upon revision based on the feedback from the validity check, the formal questionnaire (Cronbach α = 0.96) was completed. The questionnaire includes three domains: effect (Cronbach α = 0.88), attitude (Cronbach α = 0.89) and creative learning (Cronbach α = 0.89). These statistical results are supported by Camines & Zeller's theory that the reliability of a sound educational testing should be greater than 0.80 [5]. The questionnaire employs a Likert 5-point scale. After completing the activities, the survey is conducted that calls for the subjects' personal thoughts about the learning activity. A total of 56 questionnaires are distributed with a 100% rate of valid return. A one-sample t-test was used to analyze the collected data.

3.4.3 Document analysis

According to Altheide, document analysis is the approach, process and skill-valuing conceptual development combined with the locating, identifying, retrieving and analyzing of the correlation, importance and meaning of documents [2]. The researcher collected the texts of each group from the forums, chat rooms and operation areas of the online platform for a text analysis to complement the quantitative questionnaire survey. Through the principles of qualitative data collection and analysis, the researchers were able to explore the status of the STEM knowledge application, the implementation of the TRIZ creative problem-solving tasks, and the feedback after the activities.

3.4.4 Coding principle

The qualitative data of this study came from three sources. The coding principles of the data are listed in Table 3.

(1) Discussion records from the online learning platform: the students' records of discussions and chat room dialogues during the PBL activity implementation period.
(2) Assignments from the three steps of the TRIZ: uploading the results of discussions from the three TRIZ tasks from the online learning platform.
(3) Final report: submissions of the students' final reports after the group presentations are completed.

4. Results and discussion

After six weeks of experimental instruction, the qualitative data, such as students' discussions from the online platform, the sharing of learning experiences and the written reports, were reorganized and generalized. The researchers conducted a quantitative analysis of a one-sample t-test on the questionnaires to examine the influence and effectiveness of the STEM and TRIZ integrated instruction model on student learning, attitude, and creative learning.

4.1 Analysis of the effectiveness of STEM & TRIZ integrated instruction model

The researchers categorized the collected data from the online learning platform based on categories of science, technology, engineering, and mathematics to understand how students applied the TRIZ to analyze and record information and how they incorporated the STEM integrated knowledge. Furthermore, the collected qualitative data were analyzed to ensure effective student learning and the correctness of the STEM integrated knowledge learning. Finally, a questionnaire survey was employed to explore learning attitudes and learning effectiveness.

4.1.1 Text analysis of students' learning effectiveness

Students can systematically learn STEM knowledge

In Task 1 of the TRIZ, students' analyzed characteristics of the technology system by employing STEM integrated knowledge. They also learned to conduct a systematic analysis and generalize the physical states or efficacy of a system that must be improved, thus enhancing the students' systematic learning of STEM integrated knowledge.

- *After reviewing the powerpoint of TRIZ, I still don't know how to write? (D-b3) I can teach you. It is better that all of us can do it, and we will make more progress! (D-b1) I did not understand it at the beginning. The review of examples helped. There will be a problem at first, and we can solve it by TRIZ. We should first write down the problem and the function of the components of the ship. We then can indicate the solution, such as changing some components or using the substitutes to reduce the effect of the problem. (D-b4)*

Students can effectively integrate STEM knowledge

In Task 2 of the TRIZ, the students identified the technical contradictions and further recognized the relationship among the parameters of the system characteristics, thus enhancing student integration of STEM knowledge and saving time.

- *A captain was decided. We first found the maximum loading, recorded in tables and then tested the relationship between the length of the ship body and speed. (D-i3)*
- *We designed and assembled the ship with minimum streamline resistance. The ship could easily move*

Table 3. Coding principle

Data sources	Codes	Description of coding
Discussion records from the online platform	D (Discussion)	• Codes of group: a–r (there are 18 groups with 4 members in each group. Using group a as an example: codes of members in group a are a1–a4) • Tasks of three stages are represented by 1–3.
Tasks of three stages	H (Homework)	• For instance: (D-a1) indicates the discussion record from the platform of the first member in group a.
Written reports	R (Report)	(H-b-1) indicates task at the first stage of group b.
Products	P (Product)	(R-c) indicates written report of group c. (P-k) indicates the work of group k.

forward during sailing. There was no contradiction between speed and loading (D-q1).

- *For the concern of the expected conditions of the ship (solidness, loading, speed. . .), we decided to select the materials through the online chat room after school. In the next week, we will test the loading and stability of the materials, and then select the most suitable materials as our subjects. (D-g1)*

Students can refine the STEM knowledge application

By the contradiction matrix and the 40 principles of the TRIZ in Task 3, the corresponding invention principle can be immediately recognized. Through analogy, the application of the STEM integrated knowledge was more efficient. Students can, thus, creatively solve for technical contradiction and develop innovative skills.

- *Speed of twin hull structure is prominent. Thus, concerning the speed, it is necessary to study the twin hull. We have the materials for the ship, and we only have to finish the trial and test! (D-n1)*
- *Over action principle (lowest harm) (D-i2) Construct streamline body of ship by "universal principle". (D-i1)*

Students can share and exchange their STEM knowledge

In the project activity, qualitative data, such as discussions in the online learning platform, sharing of learning, and written reports, were reorganized into "observations of the STEM platform" (Table 4) to probe the students' application of STEM knowledge in the competition. Generally speaking, the most discussed topic by the students was the technology and techniques to fulfill creative works (34.9%), followed by discussions about material selection and engineering concepts of structure design (31.0%), scientific concepts (17.8%) and mathematics, such as sailing speed, stability and loading of the pneumatic propeller ship (16.3%). The discussions demonstrate that students mostly exchanged concrete and technical concepts rather than abstract thoughts.

According to the data, through the guidance of TRIZ task 1, discussions on STEM knowledge learning and application were relatively even, as shown in Fig. 6, demonstrating that TRIZ creative learning enhances STEM integrated learning. The researchers compared the written reports with the outcomes of the competition. As high school students have better basic competence in science and mathematics, their engineering design ability is more significant for this analysis. However, the main performance factor in this competition is the technology competence needed to complete the project. Without the proper technique, the ships would easily shift in different directions. As students lacked practice in technology in their previous studies, the application of technology and engineering knowledge was more difficult for them, particularly the technology component. Therefore, students had more discussions on technology and engineering. Although the students spent more time and effort on discussions of technology techniques, the sailing stability of the ships was still unsatisfying.

4.1.2 Questionnaire analysis of student learning effectiveness

As shown in Table 5, regarding student learning effectiveness, the means for the items are above 3.55 and the standard deviations are below 0.774. These statistics indicate that students identified more with the positive responses in the questionnaire. The items are significant, and the scores are above 3 (medium to high). The scores for a16—"pneumatic propeller ship practice is important learning experience for me", a4—"it is a challenge to finish the learning activity of pneumatic propeller ship" and a10—"pneumatic propeller ship practice can enhance DIY competence" are the highest (M = 4.63, 4.52 and 4.50, respectively). In addition, the score for a15—"pneumatic propeller ship practice can enhance the learning of mathematics skills" is the lowest; however, the agreement is 3.55. According to the scores, students a have positive attitude toward the learning effectiveness of the STEM & TRIZ integrated instruction model. Thus, most of students were satisfied with the cultivation of problem-solving skills, DIY, data collection and analy-

Table 4. Observation record of STEM platform at different stages

Forum/STEM	Science (S)	Technology (T)	Engineering (E)	Mathematics (M)	Total
Task 1—Analysis of technology system	28	32	27	21	108
Task 2—Description of technical contradiction	7	10	9	3	29
Task 3—Solution of technical contradiction	3	10	8	2	23
General discussion (Creative design and test improvement)	25	72	66	32	195
Total	63 (17.8%)	124 (34.9%)	110 (31.0%)	58 (16.3%)	355 (100%)

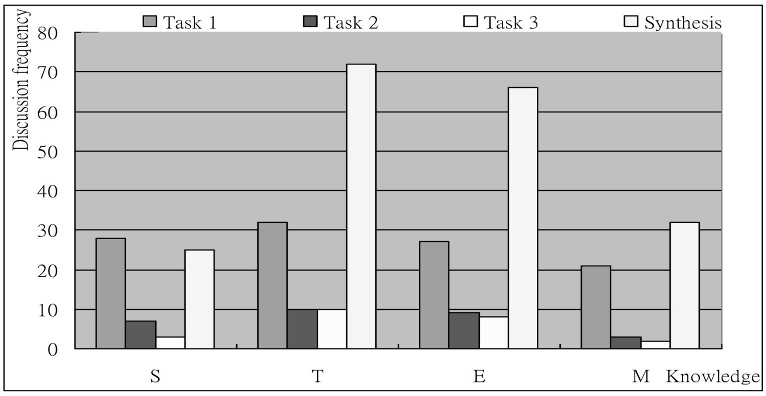


Fig. 6. Bar chart of STEM knowledge application frequency at different stages.

tical competence as well as their degree of learning effectiveness of science, technology, engineering, and mathematics.

As a result, student learning effectiveness can be enhanced using the TRIZ to guide them in the application of basic science and math concepts, engineering theory, and technology, thus cultivating the students' ability to integrate STEM instruction. Furthermore, learning effectiveness is also improved through the PBL competition activity and the discussion mechanism of the online learning platform. These results are supported by Lou et al. [20], who found that actively participating in the project develops a positive attitude toward learning. In order to produce higher quality of products, students would actively apply STEM knowledge to complete the tasks and products through discussions and creativity.

4.2 Analysis of students' learning attitudes when using the STEM & TRIZ integrated instruction model

Qualitative data from the discussions and chat rooms within the online learning platform and

Table 5. Analysis on t test of one-sample t test of learning effectiveness

		N = 56/Test Value = 3		
	Learning effectiveness	**Mean**	**Standard deviation**	**t**
a1	I learn more from the "learning activity of the pneumatic propeller ship" than from the teachers' lectures.	4.09	0.745	10.937**
a2	The "learning activity of the pneumatic propeller ship" enhances my knowledge related to research topics.	4.30	0.658	14.817**
a3	I learn new knowledge from other the students' reports.	4.09	0.668	12.200* *
a4	It is a challenge for me to complete the "learning activity of pneumatic propeller ship".	4.52	0.687	16.526**
a5	Pneumatic propeller ship practice allows me to validate theory and practice.	4.23	0.687	13.415**
a6	Pneumatic propeller ship practice is a kind of learning method with knowledge integration.	4.20	0.644	13.894**
a7	Practice of pneumatic propeller ship enhances my ability to solve problems.	4.36	0.699	14.534**
a8	Pneumatic propeller ship practice can enhance my data collection competence.	4.07	0.759	10.559**
a9	Pneumatic propeller ship practice can enhance my data analysis competence.	4.16	0.757	11.468**
a10	Pneumatic propeller ship practice can enhance my DIY competence.	4.50	0.603	18.615**
a11	Pneumatic propeller ship practice can enhance my learning of information competence.	3.98	0.774	9.491**
a12	Pneumatic propeller ship practice can enhance my learning of science competence.	4.13	0.689	12.215**
a13	Pneumatic propeller ship practice can enhance my learning of technology competence.	4.18	0.690	12.775**
a14	Pneumatic propeller ship practice can enhance my learning of engineering competence.	4.21	0.706	12.868**
a15	Pneumatic propeller ship practice can enhance my learning of mathematics competence.	3.55	0.737	5.624**
a16	Pneumatic propeller ship practice is an important learning experience for me.	4.63	0.524	23.189**

* $p < 0.05$; ** $p < 0.01$.

from group written reports were analyzed to understand the students' learning progress when applying the TRIZ to STEM knowledge. A questionnaire survey was also conducted to investigate the students' learning attitude. In this study, the researchers attempted to induce the results of qualitative and quantitative data to better understand the changes in students' attitudes during the learning process.

4.2.1 Text analysis of students' learning attitude

Students can build positive learning attitudes

Through TRIZ creative learning, students systematically recognized the manufacturing of pneumatic propeller ship and STEM integrated knowledge. It allowed the students to construct a positive learning attitude, effectively apply STEM knowledge to innovative invention of TRIZ and further develop active problem-solving competence.

- *The manufacturing of a ship body with the motor does not guarantee the successful sailing of the pneumatic propeller ship. Rather, it relies on precise calculations and studies of various theories (R-k).*
- *At first, I participated in this activity because of curiosity about ships. I thought it might not be difficult to assemble some boards. However, after joining in the activity, I realized that it was not that easy, and it was challenging (R-j).*

Students can increase learning interests and gain a sense of achievement

After practicing the TRIZ creative learning techniques, students learned the keys behind manufacturing and improving the function of their ships, thus gaining a sense of achievement. In this way, the students' active learning of STEM integrated knowledge is, thereby, enhanced.

- *I dealt with the cabin today, I cut the thick paper board into long strips and I manufactured the rectangle cabin using them. These are refined components, and the errors might destroy the thick paper board. I am really proud of my handiwork (D-a2).*
- *In the process of ship making, I realized the importance of teamwork, and I learned to solve problems by scientific experiment and technical theory. With this experience, I believe that we can deal with things based upon such scientific spirit in the future (R-i).*

Students can recognize the importance of teamwork

In the activity, students shared their experiences related to manufacturing and learning, they exchanged knowledge and they further recognized the importance of teamwork. They overcame obstacles and made a significant effort to demonstrate their creative works. Thus, students learned to actively discuss with each other, to absorb knowledge, and to solve problems.

- *In this activity, I not only learned STEM knowledge related to pneumatic propeller ship and learned to solve problems by the TRIZ, but I also recognized the importance of "teamwork". Everyone cooperated with each other and contributed. It was more efficient than individual work (R-j).*
- *By manufacturing a pneumatic propeller ship, I understand the principles, gained STEM knowledge and knowledge of the TRIZ and the importance of the cooperation among classmates. Each project took time and effort, and we should overcome some obstacles. Failure is not a big deal and what is important is our progress in learning! The members of the group constantly discuss with each other and make efforts to produce the work. We not only recognize the secret of science, but also realize "the power of teamwork" (R-b).*

4.2.2 Questionnaire analysis of students' attitude toward learning

As shown in Table 6 with respect to students' attitude toward learning, the means of the items are above 3.66, and the standard deviations are below 0.859, thus suggesting that most of students responded positively to the appropriate items in the questionnaire. The items are significant, and the scores are above 3 (medium to high). The score for b18—"In the practice of the pneumatic propeller ship, I intend to spend more time and effort on data collection, reorganization and analysis and to solve problems by way of experimentation" is the highest (M = 4.05). The scores for b20—"In the practice of the pneumatic propeller ship, when encountering problems, I will actively consult teachers, relatives, friends and experts" and b23—"If given the opportunity, I will be willing to participate in project activities on different topics" are high (4.02). In addition, the score for b19— "In the practice of the pneumatic propeller ship, I actively participate in online platform discussions and knowledge sharing" is the lowest; however, agreement is 3.66. According to the scores, students have positive attitudes toward the STEM & TRIZ integrated instruction model of creative courses, and they are willing to learn. The majority of the students are positive about their active data collection and analysis, and when encountering problems, they discover solutions by seeking the guidance of teachers and by actively engaging in the activity.

The findings of this study reveal that students can be motivated to become active learners with positive learning attitudes with the TRIZ to guide their STEM knowledge learning through PBL activities.

Table 6. Analysis of a one-sample t-test on learning attitudes

		N = 56 / Test Value = 3		
	Learning attitude	**Mean**	**Standard deviation**	**t**
b17	During the practice of the pneumatic propeller ship, I have developed a more serious learning attitude.	4.00	0.739	10.132**
b18	During the practice of the pneumatic propeller ship, I intend to spend more time and effort on data collection, reorganization and analysis and to solve problems by way of experiments.	4.05	0.773	10.203**
b19	During the practice of the pneumatic propeller ship, I actively participate in online platform discussions and knowledge sharing.	3.66	0.859	5.758**
b20	During the practice of the pneumatic propeller ship, when encountering problems, I will actively consult with teachers, relatives, friends and experts.	4.02	0.820	9.289**
b21	I apply the skills of the project study to other unknown things.	3.80	0.585	10.275**
b22	I am willing to recommend the project activity to other classmates.	3.93	0.759	9.151**
b23	If given the opportunity, I will be willing to participate in similar project activities on different topics.	4.02	0.751	10.149**

* $p < 0.05$; ** $p < 0.01$.

This is supported by Lou's [20] findings that students can easily learn and use the knowledge gained through PBL activities. Additionally, the students' willingness to unite, cooperate, and support each other, along with their feelings of indomitability are enhanced as a result of the implementation of the STEM & TRIZ integrated instruction model.

4.3 Effects of the STEM & TRIZ integrated instruction model on students' creative learning

Qualitative data from discussions in the online learning platform were divided into four groups, that is, TRIZ task 1, task 2, task 3, and synthesis discussion to better understand students' application and integration of the TRIZ and STEM knowledge. The researchers also further analyzed and compared the qualitative data with the results of the survey questionnaires to obtain more objective and authentic results of the study.

4.3.1 Text analysis of the effectiveness of students' creative learning

Students' innovation and creativity are enhanced

By observing the records of the STEM platform at different stages (Table 4), the researchers examined the discussions of STEM knowledge application in tasks during different stages of the TRIZ. Figure 7 shows that discussion frequency during the general stage is at its highest (195 times) and that frequency progressively declines with each subsequent task (task 1: 108 times, task 2: 29 times, and task 3: 23 times), which met the characteristics of the TRIZ. In the analysis and discussion of the technology system in task 1 (30.4%), the students recognized the problems and confirmed the technical contradiction of task 2 (8.2%). Through the TRIZ tools in task 3, the corresponding invention principle was immediately and efficiently recognized (6.5%). During the general stage, the students improved and completed the creative works (54.9%). The TRIZ creative learning technique guided the students to efficiently apply STEM knowledge to improve and fulfill their creative projects.

Students' innovative skills are developed and enhanced

The researchers reorganized the works of the students in each group at the second stage of the TRIZ and analyzed the students' use of 39 engineering parameters in the contradiction matrix of the TRIZ. According to Fig. 8, students applied No. 13—"the stability of components of the object" the most (8 times) and No. 1—"the weight of the moving object", No. 9—"the speed" and No. 31—"the side effect of the system" equally at 7 times. This demonstrates that students can control the key problems by implementing the TRIZ tools and can further learn the related STEM knowledge to enhance their innovative skills. In addition, the research demonstrates that the STEM applications in the TRIZ creative learning encourage students to actively explore and learn unfamiliar fields that lead to learning the STEM integrated knowledge and develop the students' innovative skills.

- *In less than two months, we not only absorbed the unfamiliar knowledge, such as TRIZ contradiction, 40 principles and calculation of loading and water displacement of ships, but also learned to express our opinions and accept others' views. We thus obtained the knowledge that could not be learned from textbooks. (R-d)*
- *We gained the experience and growth that could not be passed on by spending so much time and effort. After this participation, I learned knowledge*

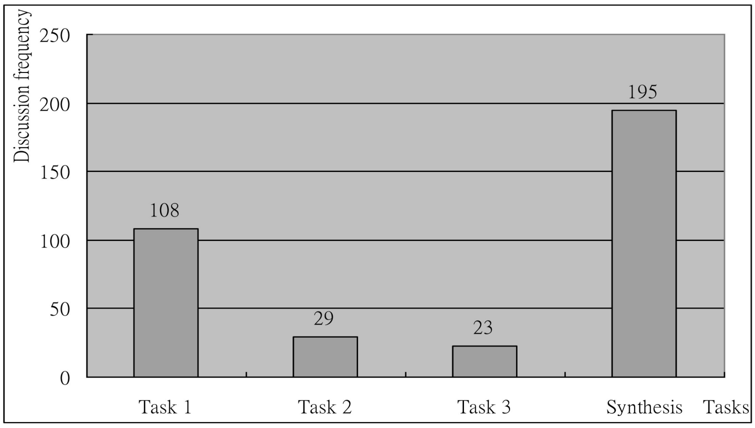


Fig. 7. Bar chart of the frequency of discussions on the STEM knowledge platform at different stages.

related to ships and application. I also recognized the precious time and knowledge beyond textbooks. (R-g)

Students can effectively integrate the TRIZ with STEM knowledge learning

Students learned to identify the feasible invention principles with the TRIZ tools, designed the best works by employing their knowledge of STEM and their creative skills and successfully completed the project according to the design process. They came to realize that the finished projects are the result of a series of efforts and experiences based upon failure (Table 7).

- *We first discussed the items undertaken for the efficiency of work division. (R-b)*
- *There were three trials, including one overturn and two right shifts. In the overturn, the ship was dipped from the edge of the paper. Therefore, we discussed this part (D-n1). Electric wire should be extended as the battery must be placed at the core so that the ship would not overturn... The ship must be stable to move fast. (D-n2)*
- *However, after several trials, we still failed. We hope that the next ship will be successful (D-n1). We have finished the previous ships, and we will test the speed and the loading of them. (D-n2)*

4.3.2 Questionnaire analysis of the effectiveness of students' creative learning

As shown in Table 8, regarding the effectiveness of the students' creative learning, the means for the

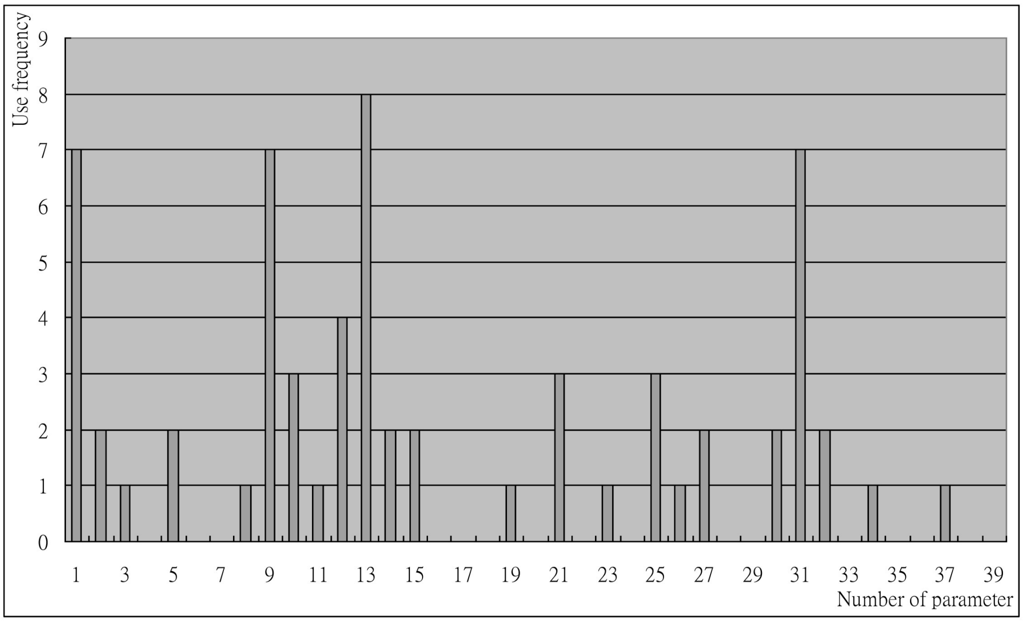


Fig. 8. Bar chart of use frequency of the 39 engineering parameters of the TRIZ.

Table 7. Manufacturing process and presentation of creative works

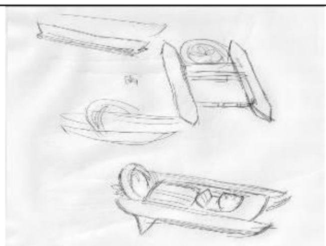
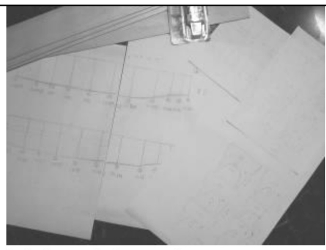
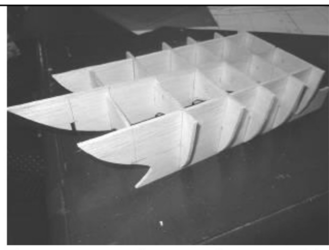
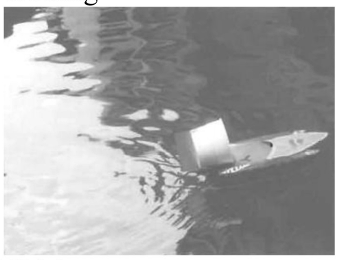
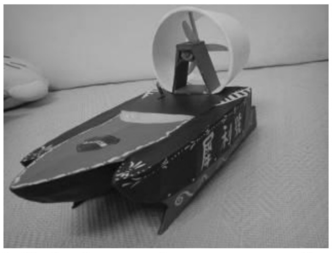
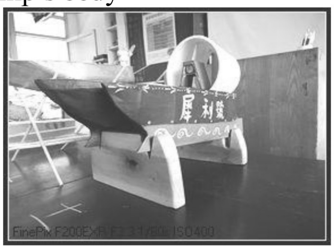
Photos of manufacturing	 1.Drawing of the blueprint	 2.Materials and pattern drawing	 3.Pattern cutting and assembly
	 4.Finishing the cover of the ship's body	 5.Trial on water	 6.Coloring and water-proof paint
Photos of presentation			

Table 8. Analysis of one-sample t-test on creative learning

		N = 56 / Test Value = 3		
	Creative learning	**Mean**	**Standard deviation**	**t**
c24	The activity allows me to recognize the content of the TRIZ.	3.71	0.762	6.902**
c25	The activity helps me to recognize the three steps of innovative problem solving of the TRIZ.	3.73	0.751	7.300**
c26	I can analyze a technology system (step 1 of innovative problem solving).	3.57	0.710	6.024**
c27	I can explain a technical contradiction (step 2 of innovative problem solving).	3.59	0.708	6.230**
c28	I can solve a technical contradiction (step 3 of innovative problem solving).	3.57	0.759	5.631**
c29	The activity allows me to recognize engineering parameters in a contradiction matrix.	3.46	0.894	3.888**
c30	I can use a contradiction matrix.	3.50	0.894	4.183**
c31	The activity allows me to recognize 40 principles of innovative invention.	3.63	0.865	5.409**
c32	I can find the corresponding innovative invention principles with a contradiction matrix.	3.55	0.784	5.281**
c33	The activity enhances my ability to focus on innovative invention.	3.86	0.773	8.299**
c34	The TRIZ reduces the time needed by our group for innovative design.	3.52	0.831	4.663**
c35	The TRIZ focuses our group's attention on innovative design.	3.50	0.739	5.066**
c36	The activity enhances my potential for creative thinking.	4.05	0.699	11.286**
c37	The activity allows me to develop my creative thinking skills.	3.95	0.749	9.458**
c38	The activity allows me improve my attitude about creative thinking.	4.00	0.809	9.250**
c39	I can repetitively practice the three steps of innovative problem solving of the TRIZ: analysis of technology systems, description of technical contradiction, and solution of technical contradiction.	3.36	0.862	3.101*

* $p < 0.05$; ** $p < 0.01$.

items are above 3.36, and the standard deviations are below 0.894, thus indicating that most of the students responded positively to the questions in the questionnaire. The items are significant and the scores are above 3 (medium to high). The score for c36—"The activity enhances my potential to think creatively" is the highest (M = 4.05). Scores for c38—"The activity allows me to have the proper attitude to think creatively", c37—"The activity allows me to cultivate the skill required for creative thinking" and c33—"The activity helps me to focus my thinking on the task of innovative invention" are high (4.00, 3.95 and 3.86, respectively). In addition, the score for c39—"I can repetitively practice the three steps of innovative problem solving of the TRIZ: analysis of technology system, description of technical contradiction, and solution of technical contradiction" is the lowest. However, agreement is 3.36. According to the scores, the students' experienced positive and effective creative learning as a result of the STEM & TRIZ integrated instruction model. Therefore, most of the students agreed that their creative thinking skills and potential had been positively impacted. Accordingly, through this activity, they developed the competence to think more creatively and to better focus their thinking on a specific objective.

The findings reveal that student creativity and efficiency are enhanced through the application of the three TRIZ tasks, including technology system analysis, contradiction confirmation, and identification of related inventive principles as well as the application of STEM knowledge to creatively design products. The results are also in accordance with Chung's perspective [21] that students' learning efficiency and active learning can be enhanced through a learning platform. Furthermore, students can increase their knowledge creativity and problem-solving techniques by sharing their knowledge and experience and thus efficiently promote research and innovation.

5. Conclusions and suggestions

5.1 Conclusions

Based on the discussions and analyses presented herein, the following conclusions have been drawn:

(1) The STEM & TRIZ integrated instruction model can systematically promote students' knowledge integration and application of STEM.

The results of learning effectiveness for students indicate that the STEM & TRIZ instruction model can systematically guide students to learn STEM knowledge, effectively promote the students' STEM knowledge integration, and increase STEM knowledge sharing and exchange.

(2) Applying the TRIZ creative learning to STEM knowledge learning has a positive influence on student learning and learning attitude.

The results of the learning effect questionnaires show that the students had positive feelings about the STEM & TRIZ instruction mode. Most of the students were satisfied with the cultivation of problem solving skills, hands-on practice, data collection, and analytical ability as well as with the learning effects of engineering and mathematics. Additionally, the results of the learning attitude questionnaires indicate that the students had positive attitudes toward the STEM & TRIZ integrated instruction model and their learning. Most of the students were able to cultivate problem-solving and data analysis skills through the instructor's guidance and activities.

(3) The STEM & TRIZ integrated instruction model enhances students' positive learning attitudes and increases their interest in learning.

The results of the learning attitude analysis show that the TRIZ & STEM integrated instruction model can assist students in developing a positive learning attitude and can increase their learning interests, thus promoting a sense of achievement and recognition of the importance of teamwork.

(4) The STEM & TRIZ integrated instruction model enhances student creativity efficiency and cultivates innovative skills.

The results of creative learning reveal that the TRIZ & STEM integrated instruction model can enhance the efficiency of the students' creativity and innovation skills while integrating the students' STEM knowledge to learn effectively.

(5) There is a positive influence on creative learning when applying TRIZ creative learning strategies to STEM knowledge learning.

The results of this study indicate that the students possess positive attitudes toward the STEM & TRIZ instruction model for creative learning. Most of the students agreed that the integrated instruction model can assist them in cultivating creative thinking potential and skills.

5.2 Suggestions

According to the conclusions and with respect to the future implementation of STEM and creative project learning, the researchers present the following suggestions for schools, teachers, and future studies.

(1) Schools: Implement the STEM & TRIZ integrated instruction model as developed in this study.

According to the research findings, the STEM & TRIZ integrated instruction model positively influences the students' learning of STEM knowledge, as students lack prior knowledge of STEM.

(2) Teachers: Increase professional knowledge of STEM instruction and the TRIZ and adopt the role of a guide.

This study demonstrates that the STEM & TRIZ instruction model can effectively enhance students' integration and application of STEM knowledge. It is suggested that teachers can help students develop balanced STEM knowledge learning by advancing their professional knowledge of STEM instruction and the TRIZ.

(3) Future studies: Expansion of research subjects.

This study was implemented as an experimental instruction case study. Although the results show that the students' learning attitude is positive and the effectiveness of creative learning is significant, it is suggested that an experimental group be included to further explore the students' learning motivation and the effects of cooperative learning for reference of future STEM instruction and activity design.

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