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Creative Problem-Solving and Creativity Product in STEM Education

Jakkrit Puchongprawet
Chulalongkorn University, Thailand, *jakkrit.p@chula.ac.th*

Pornthep Chantraukrit
Chulalongkorn University, Thailand, *pornthep.ch@chula.ac.th*

This research aims to study and compare students' creative problem-solving ability and the quality of students' creative products before, during and after the study in STEM education with the emphasis on the engineering design process. This research is an experimental One-Group Repeated Measures design, with the target groups being 72 junior high school students. The data collection tools used are 1) a creative problem solving competency test with a validity of .817 and 2) an evaluation form for the quality of creative products with a validity of .993. The data were analysed using arithmetic mean, standard deviation and repeated measures ANOVA. The research findings are as follows: 1) The difference between students' creative problem-solving ability measured after the study and their creative problem-solving ability measured during the first and second study as well as before the study was statistically significant at the level of .05, with the level of ability being high; and 2) the difference between the quality of students' creative products after the study and that during the first study and before the study was significantly significant at the level of .05,. The quality of the products was good.

Keywords: creative problem-solving ability, creative products, STEM education, engineering design process, science education

INTRODUCTION

STEM education covers learning activities that wholly integrate science, technology, engineering and mathematics and is applicable in daily life. It creates a network of learning experiences that students can draw from and apply them in life in a practical way. This concept was first introduced to the K-12 education system in the U.S. (Dejarnette, 2012). It helps students achieve STEM literacy by 1) raising their awareness of the roles science, technology, engineering and mathematics play in modern society 2) familiarizing themselves with basic concepts and 3) gaining the ability to apply knowledge in a practical way. In addition, STEM education encourages students to become problem solvers and innovators and equips STEM personnel with the ability to change the country in a positive way in the future (Honey, Pearson, & Schweingruber, 2014: 33-34)

The "E" in STEM education stands for engineering, as in the engineering design process, which encompasses design, planning, problem solving under constraints or according to criteria (e.g. time, money, material quality production capacity and environmental impacts) (Honey, Pearson, & Schweingruber, 2014: 14). There were many proposed models for the engineering design process, but the one that can be properly utilized in education was developed by the University of Colorado at Boulder, the U.K., which proposed a seven-step model for the engineering design process. It comprises 1) ask (in which one makes sense of the problem under various constraints and identify needs and design limitations), 2) research (aggregate data and information from difference sources), 3) imagine (develop the most plausible solution), 4) plan (analyse and compare each concept and constraint as well as previous studies and pick the best approach to problem solving), 5) create (create

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a prototype or model), 6) test (test and evaluate the solutions or the product's efficacy by testing it) and 7) improve (make the work better and discuss ways to improve problem-solving methods or the product itself by revising or redesigning (TeachEngineering STEM Curriculum for K-12, 2018).

STEM education with the emphasis on the engineering design process is a learning management concept that helps learners achieve important skills needed in the 21st century, such as critical thinking and problem solving as well as creativity and innovation. The ability relevant to these skills that should be strengthened in students is creative problem solving, which will help them determine problems as they are as effective as possible. The creative problem-solving ability comprises four elements of action: 1) clarify (to understand the problems), 2) ideate (to come up with a variety of problem-solving approaches, 3) develop (to assess and choose the best problem-solving approach when the STEM concept is applied, and 4) implement (to survey and identify necessary resources, budget figures and the implementation that will make problem solving comes to fruition (Creative Education Foundation (2014: 8-23). People with the creative problem-solving ability are capable of effectively managing their life and tackling multiple complex problems. This ability has positive effects on their daily life and their future career. If applied to problem solving, this ability will lead to a new, unique tool, process or technique that facilitates innovation (Baumgartner, 2013; Althuizen & Reichel, 2016: 11-12) and problem-solving outcomes that lead to the creation of creative products. According to Besemer & O'Quin (1999), there are three dimensions to the evaluation of creative products: 1) novelty, which takes into account the novelty of materials, process, approaches and product creation methods; 2) resolution, which takes into account the product's characteristics or the product's effectiveness; and 3) refinement and synthesis, which takes into account the product's aesthetics.

According to previous research, project-based teaching has many limitations for the development of many abilities. This is because sometimes students do not choose project topics based on real problems and no clear design. **(**Ergül & Kargin, 2014**)** For this reason, I am interested in organizing learning activities in line with STEM education with the emphasis on the engineering design process to improve students' creative problem-solving ability and the quality of creative products, all of which are crucial to enhancing relevant skills in the 21st century in students and creating new innovations.

Research Problem

How does organizing learning activities in STEM education with the emphasis on the engineering design process help improve the creative problem-solving ability and quality of creative products?

Research Focus

1) To study and compare students' creative problem solving ability before, during and after the study in STEM education with the emphasis on the engineering design process.

2) To study and compare the quality of students' creative products after the study in STEM education with an emphasis on the engineering design process.

Review of Literature

The research is based on the following principles:

1. Learning activities in line with STEM education with the emphasis on the engineering design process

This is defined as organizing learning activities that help students achieve learning experiences that involve creating products that can be used to solve problems in everyday life, using scientific, mathematical and technological knowledge via the engineering design process, in accordance with

Teach Engineering STEM Curriculum for K-12 (2018). It comprises 1) ask, 2) research, 3) imagine, 4) plan, 5) create, 6) test, and 7) improve.

2. The creative problem-solving ability

This is defined as the ability to find answers for problems or distinctive approaches to solving problems that yield more effective outcomes than other approaches. The creative problem-solving ability consists of four elements of actions: 1) clarify, 2) ideate, 3) develop, and 4) implement according to the Creative Education Foundation (2014).

3. The quality of creative products

This is defined as the good quality of products resulting from the creative process. The attributes to the quality are novelty, practical application and refinement. There are 3 dimensions and 11 elements: 1) novelty, 2) resolution, and 3) refinement and synthesis based on the concept of Besemer & O'Quin (1999), for the assessment of creative products.

METHOD

Research Design

The study is an experimental One-Group Repeated Measures design, which measures the creative problem-solving ability and quality of creative products in four assessments divided before the study, during the first study, during the second study and after the study in STEM education with the emphasis on the engineering design process 20 periods. The target group comprised a total of 72 junior high scholars in Thailand — 41 males and 31 females — who were in the second term of the 2021 academic year. They were divided into 22 groups.

Instrument and Procedures

The research tools are as follows:

1) The creative problem-solving ability assessment form is a subject test comprising two sets of situations students must consider to solve the problems and four test items for each situation. The time limit is 60 minute. The test was administered to students four times, with each test comprising different situations. A scoring rubric was used to test the quality of the tools, which found the test has a validity value of .817, a difficulty index of .39–.59 and a discriminant index of .25–.46. The concordance correlation coefficient among three assessors was .864 – .970. When the reliability of the parallel test was measured, it was found that the correlation coefficient of all four test items for two situations ranged .811 – .855

2) The quality of creative products assessment form includes the bi-polar semantic scale, in which bipolar sentences or adjectives with seven spaces between them are provided for 40 items to assess the quality of students' creative products by the instructors in four assessments. After the tool's quality was tested, the internal consistency was equivalent to .993 and the correlation coefficient among 5 assessors ranged .768 – .990.

The tools used for this research are four educational management plans in line with STEM education with the emphasis on the engineering design process, with each plan comprising five class periods. There were a total of 20 periods. Each activity was carried out in STEM education with the emphasis on each step of the engineering design process with integrated content, as shown in Table 1.

Table 1
shows the number of class periods and the types of activities included in each education plan

No	Activity title	Assessment criteria	Integrated subjects			
			Science	Mathematics	Technology	Engineering
1	Sizing equipment	Precision and speed of sizing	1. Friction 2. Speed	1. Slope 2. Cost calculation	1. Tool selection 2. Data query technology	1. The 7-step engineering design process
2	Turbine for power generation	The amount of electricity	1. Electrical circuit 2. Moment of force 3. Energy	1. Cost calculation		
3	River bridge	Load carrying capacity	1. Resultant force 2. Force distribution 3. Weight	1. Geometric forms 2. Cost calculation		
4	Flood boat	Load carrying capacity	1. Density 2. Buoyant force 3. Moment of force	1. The volume of an object 2. Cost calculation		

Analysing of Data

The arithmetic mean, average percentage score, standard deviation, repeated measure ANOVA and open-ended questions were used

FINDINGS

The results of the analysis of comparative data on the creative problem-solving ability

The basic statistical value and the levels of target students' creative problem-solving ability were (n = 72), based on four assessments, as shown in Table 2.

Table 2
The basic statistical value and the levels of target students' creative problem-solving ability were (n = 72), based on four rounds of assessment (The full score is five)

time	basic statistics	*component of the creative problem-solving ability*				*average scores*
		1(Clarify	2(Ideate	3(Develop	4(Implement	
before the study	*M*)*SD*(	2.87)0.77(	2.60)0.75(	2.83)0.89(	2.56)1.01(	2.72)0.62(
	level	moderate	low	moderate	low	moderate
during the first study	*M*)*SD*(	3.20)0.78(	2.86)0.81(	3.33)0.91(	2.84)0.62(	3.06)1.00(
	level	moderate	moderate	moderate	moderate	moderate
during the second study	*M*)*SD*(	3.72)0.82(	3.13)0.90(	3.65)1.01(	3.12)1.05(	3.41)0.78(
	level	high	moderate	high	moderate	high
after the study	*M*)*SD*(	4.08)0.80(	3.72)0.97(	4.12)0.88(	3.76)1.06(	3.92)0.81(
	level	high	high	high	high	high

According to the table, students' average scores increased in every assessment stage, with the average score recorded before the study, during the first study, during the second study and after the study being 2.72, 3.06, 3.41 and 3.92, respectively, from the full score of 5. Their competence level in each assessment stage was moderate, moderate, high and high, respectively.

After that, I compared the scores and their differences using a repeated measures ANOVA through the preliminary agreement review and Mauchly's W. It is found that the variance and covariance matrix were not Compound Symmetry (Mauchly's W = .792, Chi-Square (5) = 16.220, p = .006). In order to test the differences of scores on the creative problem-solving ability based on the four assessments, I used the Greenhouse-Geisser method. From the research results, it was found that the difference of at least one pair of scores was statistically significant, at the level of .05 (p < .001). I, thus, compared each pair of scores using the Bonferroni method to compare the average scores obtained from four assessments, as shown in Table 3.

Table 3
The results of comparing the differences of average scores of the creative problem-solving ability, based on four assessments

time	$\bar{x}$	before the study	during the first study	during the second study	after the study
1(before the study	2.72				
2(during the first study	3.06	0.340)*( )*p* < .001(			
3(during the second study	3.41	0.689)*( )*p* < .001(	0.349)*( )*p* < .001(		
4(after the study	3.92	1.205)*( )*p* < .001(	0.865)*( )*p* < .001(	0.516)*( )*p* < .001(	

* *p* <.05

Based on the results of comparing the average scores of the creative problem solving ability, the difference of the average scores in every assessment stage was statistically significant, at the level of .05.

The results of the comparative data analysis on the quality of creative products

The basic statistical value and the quality of creative products of 20 groups of student subjects (n = 20) based on four repeated assessments, as shown in Table 4.

Table 4
The basic statistical value and the quality of creative products based on four repeated measurements (the full score is 7)

time	basic statistics	*dimension of creative products* 1(novelty	2(resolution	3(elaboration and synthesis	*average scores*
before the study	*M*)*SD*(	3.28)1.39(	3.36)1.00(	3.10)1.31(	3.25)1.13(
	level	poor	poor	poor	poor
during the first study	*M*)*SD*(	4.08)1.24(	3.93)0.89(	3.70)1.39(	3.90)1.05(
	level	moderate	moderate	moderate	moderate
during the second study	*M*)*SD*(	4.51)0.91(	4.58)0.79(	4.00)0.56(	4.37)0.54(
	level	moderate	moderate	moderate	moderate
after the study	*M*)*SD*(	5.12)0.43(	4.88)0.94(	4.21)0.61(	4.74)0.45(
	level	good	good	moderate	good

Based on the Table, students' average scores improved in each trial. The average scores before the study, during the first study, during the second study and after the study were 3.25, 3.90, 4.37 and 4.73, respectively, from the full score of 7. Their products' quality in each assessment stage was poor, moderate, moderate and good, respectively.

After I tested the score differences by conducting the repeated measures ANOVA through a basic assumption test using Mauchly's W, I found that the variance and covariance matrix were Compound Symmetry (Mauchly's W = .638, Chi-Square (5) = 7.951, p = .160). Hence, to test the differences of the scores for creative products' quality from four repeated measures, I used the assumption of sphericity. From the research results, it was found that the difference of at least one pair of scores was statistically significant, at the level of .05 (p < .001). I, thus, compared each pair of scores using the Bonferroni method to compare the average scores obtained from four repeated measurements, as shown in Table 5.

Table 5
The results of comparing the average scores of the quality of creative products based on four repeated measurements.

time	$\bar{x}$	before the study	during the first study	during the second study	after the study
1(before the study	3.25				
2(during the first study	3.90	0.656)*p* = .268(			
3(during the second study	4.37	1.118)*( )*p* = .004(	0.462)*p* = .507(		
4(after the study	4.73	1.487)*( )*p* < .001(	0.831)*( )*p* = .014(	0.369)*p* = .185(	

* *p* <.05

The differences of the average scores before the study and during the first study, during the first study and during the second study, and during the second study and after the study were not statistically significant, at the .05 level. But the differences of the average scores before the study and during the second study, before the study and after the study, and during the first study and after the study were statistically significant, at the .05 level.

CONCLUSION AND DISCUSSION

From the research results, it was found that the creative problem-solving ability and the creative products' quality increased when the students studied in STEM education with the emphasis on the engineering design process. The results can be discussed as follows:

The study and comparison of the creative problem solving ability

According to the study, the average scores of the creative problem solving ability in every study period rose and were significantly different at the level of .05. The scores of all elements of the creative problem-solving ability were high, due to the following reasons.

First, learning activities in STEM education make it convenient for students' to integrate multiple academic subjects to solve problems in everyday life in a systematic way and in accordance with the engineering design process under certain constraints. Students will be able to identify problems and come up with various approaches to solve them in the most creative and appropriate way. This goes in line with the concepts by Bybee (2013: 5) and Honey, Pearson, & Schweingruber (2014: 33-34), which suggest STEM education helps students become problem solvers in the 21st century and develop STEM literacy, which – in turn – will prepare them for solving problems that require scientific, mathematic and technological skills.

Second, each element of students' creative problem-solving ability will develop under the engineering design process, which forms part of STEM education. The elements are as follows:

1) The element of identifying problems with clarity will improve through the questioning process of STEM's engineering design process. Students will practice their analytical skill through the WhyWhy technique, 5W1=H or mind mapping. They will help students gain insightful perceptions into the problems they face and approach them from a different perspective, in line with Science Buddies' (2019) concept.

2) The element of concept exploration will be developed in the problem investigation and imagination stage, which enable students to design various approaches through the round robin technique enhanced by the SCAMPER technique. Students will be able to apply other ideas to existing ones in a variety of ways, in line with the creativity development guidelines by Treffinger, Isaksen, & Stead-Dorval (2005: 13), which emphasize the importance of having multiple options available before a decision on solving a problem is made.

3) The element of developing problem solving methods will improve in the planning process, in which students choose the best option to solve problems with discretion through the Evaluation Matrix technique and Sequencing: SML, in line with the concepts by Treffinger, Isaksen, & Stead-Dorval (2005: 13).

4) The element of troubleshooting will improve as part of the creation of prototypes to test the efficiency, which will help analyse the suitability, strength and applicability of students' problem-solving approaches. The prototypes take into account the benefits and limitations of problem-solving approaches, in line with the concepts by Haik, Y., Sivaloganathan, S., & Shahin, T. M. (2015: 29).

The study and comparison of the creative products' quality

The study found that the average scores of creative products' quality increased in every study period. There was a significant difference in scores, at the level of .05, in trial periods with long intervals between them. However, there was not a significant different in scores, at the level of .05, in trial periods with short intervals between them. Uniqueness and problem-solving were rated highly. Refinement was rated moderately, due to the following reasons.

First, STEM education involves the engineering design process that helps students draw from different product concepts to create their own product and the creation of prototypes to test the efficiency. Students will be able to turn knowledge into concrete products to solve problems in a fresh, effective and refined way, which will lead to innovation development in the future, in line with the concepts by Bybee (2013: 5) and Honey, Pearson, & Schweingruber (2014: 33-34), which suggest STEM education can turn students into innovation creators.

Second, refinement and post-study synthesis were rated moderately, possible due to the time constraint on students' creation. Moreover, junior high schoolers had fewer scientific and mathematic experiences and were not able to fully apply concepts. As Besemer & O'Quin (1999) suggested, refined products were not created with haste and required integrated knowledge.

In conclusion STEM education with the emphasis on the engineering design process can develop creative problem-solving ability and the quality of students' creative products that are essential skills in the **21**st century.

RECOMMENDATIONS

Recommendation for using research findings

STEM education with the emphasis on the engineering design process takes into account students' basic knowledge level, so that knowledge can be integrated for product creation. The number of students should also be limited to ensure everyone can be supervised by the instructor. In addition, if additional teaching techniques were included in each step of the engineering design process, students' performance could improve.

Recommendation for further research

Based on an observation on students' teamwork competence in STEM education with the emphasis on the engineering design process, students' teamwork skill improved. Their ability to work in their assigned role also improved. For this reason, research on collaborative problem-solving development in STEM education or creative and collaborative problem-solving development can be conducted.

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