The Impact of Project-based Learning Integrating STEM on Vocational School Students' Creativity in Mathematics

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Abstract

The STEM integrated learning is a program that combines two or more fields of science contained in STEM, i.e. 'Science, Technology, Engineering and Mathematics' to involve students in defining and formulating a solution to authentic problems in the real world. This article reports the findings of a quasi-experimental one group pretest posttest design, aimed at examining the effect of project-based learning integrating STEM on mathematical creative thinking abilities. The study involved 36 students of a vocational school, and used a set of creative thinking skills tests and a survey questionnaire, as well as observation guidelines and interviews as instruments. The analysis of findings reveals that the average achievement of students' creative thinking abilities after the input of project-based learning integrating STEM increased compared to before the input, as analysed using the Wilcoxon-marked rank test which showed the differences in achievement abilities before and after learning that differed significantly. This means that the application of project-based learning integrating STEM was carried out effectively in improving students' creative thinking abilities. The results of descriptive data analysis show the increase of students' ability to think creatively based on the Beginning Mathematical Ability (BMA) survey in which at all levels of BMA, the ability of students is in the high and medium categories. There are positive results from the analysis of the data extracted from the questionnaire, interviews and observations. Hence the application of project-based learning integrating STEM at vocational high schools is highly recommended.

Keywords: *STEM; Project-based learning; Mathematical creative thinking skills*

Introduction

The STEM integrated learning is a program that combines two or more fields of science contained in STEM, i.e. 'Science, Technology, Engineering and Mathematics' (Laboy-Rush, 2010). The center of various activities in this program is to involve students in defining and formulating a solution to authentic problems in the real world.

Project-based learning integrating STEM education helps students bridge the mathematical knowledge learned in school with the real world. The integration between several fields of

science (mathematics with technology and engineering) in STEM project-based learning helps students give the meaning that mathematics is closely related to other fields of science. This is in accordance with the culture in vocational high schools where in general students are required to be able to practice various theoretical sciences they obtain in class.

Background and Overview

The current era of globalization has changed almost all order of human's life in the world. The structure of people's lives changes rapidly as information and communication rapidly change. In this fast-changing world, creativity becomes an important aspect that determines one's excellence. According to Alexander (2007), an individual's success is determined by his creative abilities in solving problems, both large and small scale. The importance of aspects of creativity for human's survival, making the study of creativity become an important topic for various groups ranging from public policy makrs, scientists, researchers, to practitioners.

The term creativity can be found in old manuscripts from ancient Greek and Roman times (Treffinger, 2002). Discussions on the issue of creativity among educators, psychologists and modern researchers began in the mid-20th century, namely after J.P. Guilford in 1950 who put forward this idea in the American Psychological Association forum. Since then, there have been more and more studies and research on creativity as well as its development. In the ERIC (an abbreviation of The Educational Resources Information Center) database as of October 29, 2016, there were 15,605 articles recorded for the keyword creativity.

Problem Statement and Rationale

Given the importance of creativity for one's success, fostering and practising student creativity becomes a separate agenda in the school curriculum. This is in accordance with the mandate of the curriculum which states that the competency standards of graduate students at the high school or vocational level include having the ability to think and act creatively, productively, critically, independently, collaboratively, and communicatively (Ministry of Education and Culture, 2016). It is seen that aspects of creativity become important things that need to be instilled in every learning.

Is creativity found in mathematics? Some experts believe that the answer is "Yes". Pehkonen (1997a) states that creativity is not only found in certain fields, such as art and science, but also in other fields including mathematics. Kiesswetter (Pehnoken, 1997b) suggests that the ability to think flexibly which is one component of creativity is one of the important abilities that must be possessed in solving mathematical problems. These opinions confirm that creativity is also present in mathematics.

According to Han, Capraro and Capraro (2015), myths about mathematics as difficult and frightening lessons for students are still common in our schools, including for many students in vocational schools. Mathematics as one of the lessons in adaptive groups, even though it is a compulsory subject, is often of less attention compared to productive subjects which are certainly in accordance with each student's interests. The effect is the low mathematical ability of students, including students' creative thinking abilities.

Observing the importance of creativity while the ability of our school students is still low, efforts and improvements in learning mathematics are needed. One concern is how to create a learning atmosphere that stimulates creativity so that all students are involved in learning and their motivation to solve mathematical problems in learning mathematics in the classroom can be enhanced.

At this time it is important that students are given the freedom to gain experience and understanding through learning activities obtained from observations and discoveries or experiments they make. They can also be given the freedom to use various tools as well as media technology and information, including using internet facilities to enrich their learning experience, or a means of expressing ideas. Of course things like that will increase the creativity of students in the classroom and outside the classroom.

According to Asmuniv (2015), one effort that can be done is by providing a treatment that can bring students to the level of activity and optimal creativity. The intended treatment is to apply project-based learning by integrating STEM fields, i.e. Science, Technology, Engineering, and Mathematics.

Aim of Study and Research Question

In the context of mathematics learning, the approach of project-based learning integrating STEM has the potential to provide meaningful learning, can train students' ability to solve problems through a project that is integrated with one or several other scientific fields such as science, mathematics, engineering, and technology, in addition to providing experience to students as mathematics has real benefits for life, and is around them. Daugherty (2013) said that in STEM education, the ultimate goal of learning is the result of cognitive activities (cognitive outcomes) of students in learning, which contains learning content that students expect to know.

Based on the description above, in an effort to increase student creativity steps must be taken to improve the quality of mathematics learning. This study aims to answer the following research questions:

1. How to provide learning that is rich in meaningful and creative activities so that students are more active and skilled in problem solving, especially during the implementation of project-based learning integrating STEM approach?

2. Will there be any significant effect of the application of project-based learning integrating STEM on student's creative thinking abilities?

The following null hypothesis is made:
The application of project-based learning integrating STEM has no significant effect on student's creative thinking abilities.

Literature Review

Creativity in Mathematics Learning

Creativity is often associated with the ability to produce creative product. One thing that is certain which cannot be denied is the fact that any type of creative product produced must be preceded by the generation of creative ideas. This creative idea arises from the thought process which is a form of cognitive aspects. This process is called the process of creative thinking. This process refers to individual efforts to produce creative solutions or products. Such thinking is usually triggered by challenging tasks or open-ended problems that need to be solved from various points of view.

In general creativity does not have a standard formula, nor does the term mathematical creativity (mathematical creativity). There are many experts who provide different definitions of the term mathematical creativity. However, from some references that discuss creativity leads to three main components, namely fleuncy, flexibility, and originality, and some add elaboration. These components are used by Torrance and others to define and test creativity (Sheffield, 2013).

Some definitions of creativity related to mathematics contain at least two aspects in creativity, namely aspects of the process and aspects of creative products. The creative process aspect as discussed previously refers to the creative thinking process while the creative product aspect refers to the product that is produced from the creative thinking process. Creative products as a result of creative thinking can be physical (touchable) can also be physical (untouchable) such as ideas, ideas, various solutions to problems, or formulas in mathematics.

Does one's creativity only depend on the creative thought process carried out as a form of cognitive activity? Many experts answer no to this question. It turns out that the cognitive aspects associated with intelligence are not the only absolute conditions for the growth of creativity. In the study conducted, Guilford in (Munandar, 2014) distinguished the main characteristics of creativity into aptitude traits and non-aptitude traits. Characteristics of aptitude characteristics of creativity are characteristics of creative thinking that contain cognitive aspects, while non-aptitude traits refer to creative attitudes that contain affective aspects. It can be understood that an individual's creative achievement is also determined by their creative attitude. Therefore, the development of student creativity through learning mathematics not only pays attention to the development of creative thinking abilities but also fosters attitudes and creative personality traits.

Based on the description above, the creativity reviewed in this study is seen from two aspects, namely the cognitive aspect of the ability to think creatively, and the effective aspect of the creative attitude. The aspects of creative thinking measured include fluency, flexibility, and originality. While aspects of creative attitude were adapted from Munandar (2014), including imaginative, having broad interests, having initiative, being independent in thinking, being melit, being adventurous, full of energy, confident, willing to take risks, and courageous in their convictions and beliefs.

Developing Thinking Ability and Creative Attitudes

In learning mathematics, the development of the ability to think creatively can be done through learning by using open problems or problems. Open-ended problems are problems that have many solutions or strategies for solving them (Takahashi, 2008). According to Silver (1997), the use of open problems can give students a rich learning experience in interpreting problems also allows students to produce different solutions. This condition allows students to practice aspects of creative thinking such as fluency, flexibility, and originality.

On the other hand, a learning climate that stimulates students to be active and creative in such a manner can gradually foster students' positive attitudes about creativity. The freedom and trust given to students in each learning process can increase their confidence, courage, and sense of responsibility in learning. This can be a capital for them to become creative individuals not only in the learning that takes place, but also for their real lives outside the context of learning.

Project-Based Learning Integrating STEM Education

Ritz and Fan (2014) revealed that the application of STEM education has taken place in several countries, and each has a different form in terms of its application. In Indonesia alone the integration of STEM as a learning approach is not yet very popular. Nevertheless, the concept of integration between scientific fields has begun to emerge voiced in our education curriculum, including in the 2013 curriculum. Although it does not explicitly bring up the term STEM, the concept of "integrative thematic" that appears in the 2013 curriculum indicates the need for integration of various fields of science in a learning specific field of study, and this is in line with the concept of STEM integration. The following table 1 outlines the definition of STEM literacy according to the National Governor's Association Center for Best Practices (Asmuniv, 2015).

Table 1
Definition of STEM Literacy

Science	Scientific Literacy: The ability to use scientific knowledge and processes to understand the world and nature as well as the ability to participate in making decisions for influence it.
Technology	Technology Literacy: Knowledge of how to use new technology, understanding how new technology is developed, and having the ability to analyze how new technology affects individuals, society, the nation and the world.
Engineering	Design Literacy: An understanding of how technology can be developed through an engineering / design process using project-based learning themes by integrating several different subjects (interdisciplinary).
Mathematics	Mathematical Literacy: Collection in analyzing, reasoning, and communicating ideas effectively and from how to behave, formulate, solve, and interpret solutions to problems mathematics in applying various different situations.

In the project-based learning designed in this study, STEM integration covered three fields, namely mathematics, technology, and engineering. The technology adopted is related to the use of various Information and Communication Technology (ICT) devices, namely computer and internet media. The field of engineering raised is related to one productive subject, namely web design and programming, and the field of mathematics raises the topic of statistical material. In its realization, STEM learning project-based learning that will be carried out follows the syntax of project-based learning in general, namely: (1) determination of fundamental questions, (2) compiling project planning, (3) compiling schedules, (4) monitoring, (5) testing the results, (6) evaluation of experience (Kementrian Pendidikan dan Kebudayaan, 2014).

Research Methods

Research design

The study was conducted was a quasi-experimental study (quasi-experiment) with one group pretest-posttest design (Cohen, Manion & Morrison, 2007). The population in this study were students of class X in the technology group at SMK Tunas Harapan Pati in the academic year

2019/2020, with the research sample being chosen by one class using purposive sampling technique. So, this study consists of one experimental class that gets a treatment, which is given learning with a project-based learning model through the STEM approach (Science, Technology, Engineering, and Mathematics) education, hereinafter abbreviated to STEM learning project-based learning. Before being given treatment, students in the experimental class were given a pretest problem, and after the treatment was given posttest.

Research Instruments and Sampling Techniques

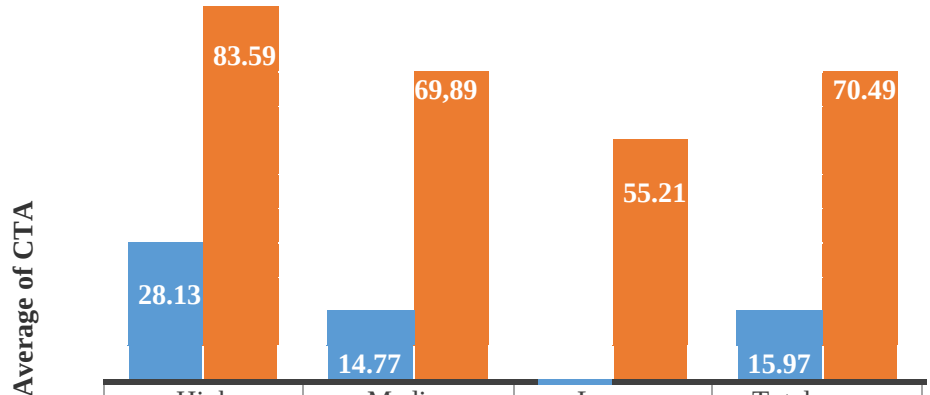
The instruments used in this study were test and questionnaire. The test instrument is in the form of a set of creative thinking ability test questions in the form of a description for open-ended responses. Non-test instruments in the form of a creative attitude scale, observation sheets, and interview guidelines. Instruments (tests and non-tests) are assessed by experts who have the ability to judge.

In addition to validation from experts, the test instrument was also piloted to students outside the experimental class students in the Vocational School where the researcher is working. This school is one of the 125 vocational schools in the area. The activity was carried out as pilot study involving one class with sample size of 36 students to determine the overall validity of the test and each item, reliability, distinguishing features, and level of difficulty. Data processing of the trial results was carried out using the Rasch Model method with the Winsteps application.

Results and Discussion

Research Data Analysis Results

The purpose of this study is to look at the significance of the application of project-based learning on students' mathematical creativity as a whole and based on Beginning Mathematical Ability - BMA (high, medium, and low), as seen from cognitive and affective aspects. The measured aspect was the ability to think creatively, and the affective aspect is the creative attitude. For this purpose, the data collected in the form of pretest and posttest scores of creative thinking abilities, and the results of students' creative attitude questionnaires. For the ability to think creatively, a normalized gain score (n-gain) is also calculated to see the quality of improvement. The data description of students' creative thinking abilities based on BMA is shown in the diagram in Figure 1 below.



	High	Medium	Low	Total
Pretes	28.13	14.77	4.17	15.97
Postes	83.59	69.89	55.21	70.49

Figure 1. Comparison of Pretest Data with Posttest Students Creative Thinking Ability Based on BMA.

Analysis was carried out to see differences in the achievement of students' creative thinking abilities before and after learning with STEM project-based learning, namely by testing the average difference for paired samples. Because the results of the normality and homogeneity tests of data variance show that the pretest data is not normally distributed, the difference test is performed with a non-parametric statistical test, the Wilcoxon marked rank test. The hypothesis on the statistical tests carried out and the summary results of the Wilcoxon marked rank test are as follows.

H_0: There is no significant difference between the application of STEM education integrating project-based learning and students' creative thinking abilities
H_1: There is significant difference between the application of STEM education integrating project-based learning and students' creative thinking abilities

Table 3
Wilcoxon Signed Ranking Test Results

Test	**Postest– Pretest**	Ho
Z	-5.265[b]	Rejected
Asymp. Sig (2-*tailed*)	0.000	

a: CTA data has a normal distribution
b: based on negative ranks

Because of value *Sig*. (2-tailed) 0.000 < ½ of 0.05 or 0.025, H_0 is rejected, meaning that the application of STEM project-based learning in mathematics learning has a significant influence on improving students' creative thinking abilities.

The results of the calculation of the n-gain score or number of gain score showed an increase in the ability to think creatively in the high BMA group (0.77), including the high category, while the increase in the creative thinking ability of the moderate BMA group (0.65) and low (0.53) was classified as the medium category. There is no increase that is classified as low.

The analysis of creative attitude scale data as shown in Table 4. obtained the results of the category of creative attitudes are in the high category (2.78%) and moderate (97.22%). Positive responses were also obtained from interviews and observations of class activities. Overall class activities are in the good category.

Table 4
Categories of Student Creative Attitudes

Class	**Category Creative Attitude**	**Frequency**	**Pecentage (%)**
STEM Education	High	1	2.78
	Medium	35	97.22
	Low	0	0

Discussion

Based on the results of the analysis of research data that has been obtained, it is found that the average achievement of students' creative thinking abilities before and after learning with STEM project-based learning is significantly different. The results of the questionnaire data analysis also showed a positive effect, that in general students felt that the applied learning was beneficial to them. This is because in STEM project-based learning students are invited to do meaningful learning in understanding a concept. Students are invited to explore through a project activity, so students are actively involved in the process. This fosters students to think critically, creatively, analytically, and improve higher order thinking skills (Capraro & Slough, 2013). Project-based learning integrating STEM education requires collaboration, communication between partners, problem solving skills, and self-management.

Data analysis based on BMA showed that the category of increased creative thinking ability was classified as high and medium, there was no group with a low category. This finding is in line with research by Han, et.al (2015) which states that the application of project-based learning STEM can improve students' mathematical achievement in various ability groups (high, medium and low).

Conclusion

Summary and Significance

Based on the results of the study as described above, it was concluded that the application of learning carried out affects the creative attitude of students. Student creativity seen from the aspects of creative thinking before and after STEM learning project-based learning experienced significant differences, and increased ability to be at a moderate level. So it can be said that STEM project-based learning is effectively carried out in mathematics learning in vocational high schools, especially in increasing students' mathematical creativity.

Descriptive analysis of the data on increasing students' creative thinking abilities based on the level of Beginning Mathematics Ability – BMA (high, medium, low) shows that at all levels of BMA the ability to increase is at high and moderate levels. Meanwhile, from the aspect of creative attitude, after learning with STEM project-based learning students' creative attitude is generally stated to be good, so based on the results of interviews and observations of student learning activities lead to the same conclusion.

Suggestions for the Way Forward

Based on the conclusions put forward, the researcher recommends that teachers in vocational schools, especially mathematics teachers, be able to apply this kind of project-based learning learning model and collaborate with other fields of study teachers, especially productive fields so that they can integrate STEM in their learning.

To the teacher or researcher who will conduct a study on the implementation of STEM in the teaching of mathematics specifically, it can be examined its effect on other mathematical abilities if it is appropriate.

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