Engineering Design Process: Cultivating Creativity Skills through Development of Science Technical Product

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Abstract. This study aims to determine the impact of the integration of engineering design (ask, imagine, plan, create and improve) in physics teaching to encourage students' creativity skills through science technical product. This quasi-experimental study was conducted on 40 form three students of secondary school in Aceh, Indonesia. Two classes were randomly selected and served as the experimental group. The results showed that the use of teaching and learning physics that integrates five steps of engineering design is more effective in developing students' creativity skills compared to the traditional method of teaching and learning physics. The teaching and learning module for the experimental group also can be used as a guide for teachers to implement the five-step integration of engineering design (ask, imagine, plan, create and improve) in the teaching and learning of physics.

Keywords: Teaching and learning module, engineering design, creativity, science technical product

INTRODUCTION

Yager and McCormack [1] have put forward the idea of taxonomy for science education is that to develop the skills and students' achievement in science. According to Yager and McCormack, the taxonomy is divided into five domains which were developed from the three-level domains of Bloom's taxonomy. The five domains of taxonomy for science education are: (a) knowledge; (b) process of science; (c) creativity; (d) attitude; and (e) application and connection. In the process of teaching and learning of science, all five domains play an important role in achieving the goals of science education. Through the mastery of the five domains, students are not only required to improve their knowledge and skills as part of creativity, but also are able to develop a positive attitude towards science and the ability to apply and make connections between science concepts learned to everyday life.

As an implementer of teaching and learning in the classroom, teachers are supposed to have the ability to ensure that all five domains of taxonomy can be encultured in a holistic way for each student. Teachers should be able to master the knowledge in selecting and applying appropriate teaching approach for achieving the five domains of the taxonomy of science education. One of the goals of science education is to produce students who have the ability to master the concepts, skills and ability to apply scientific knowledge to real life. According to Schnittka [2], the ability to understand the scientific concepts will help students to link it to the scientific phenomena and problems that occur in their daily lives and this will lead them to solve problems in science including presenting the ideas in the form of a technical product. The ability of students to apply scientific concepts in the form of technical products requires the students to think logically, critically, creatively and innovatively which are in accordance with the objectives and goals of science education curriculum such as Indonesia and Malaysia [3]-[4].

In the teaching and learning of science, there are various active teaching and learning approaches such as constructivism, contextual learning, inquiry learning, as well as problem-based learning. However, in practice, teachers rarely carried out these approaches, thus the ability of students to think logically, critically, and creatively in solving problems is unmet [5]-[6]-[7]. Therefore, by using engineering design approach as an alternative to the active teaching approaches mentioned earlier students are also able to think logically, critically, and creatively solve problems [2,8 -12].

In the secondary school education curriculum in Indonesia, physics is one of science disciplines that must be taught towards producing students who have the ability to think logically, critically, creatively, and innovatively. However, teachers face a variety of constraints and obstacles in teaching and learning thus are unable to fully achieve that goal [13]. At the level of implementation, it is found that most teachers use the lecture approach in the teaching and learning of physics, rather than using an approach that is characterized by active learning [13]. While learning though lecture is not entirely wrong, but to produce students who are knowledgeable in the application of physics concepts, and be able to think logically, critically, and creatively- appropriate teaching approach that is characterized by active learning such as the teaching of science-based design is needed [2]. Electricity and magnetism is a topic in the subjects of physics, which is considered difficult by most teachers [13-15] as it used as a main topic in this study.

This study aims to develop a module of teaching and learning physics that are arranged in a planned, systematic, and explicit way involving the five-step approach to engineering design (ask, imagine, plan, create, and improve). The engineering design was integrated with the overall teaching approach which was Needham five phases - orientation, triggering idea, restructuring ideas, the ideas, and reflection. Teaching and learning of science-based engineering design is a teaching and learning process that can train students to become better thinkers [16]. By following learning activities based on engineering design, students will learn how to analyze the situation and gather relevant information, define problems, evaluate and generate ideas creatively, develop ideas to solve problems effectively, and assess and make improvements to the solution [17].

This is in line with the function and purpose of learning science itself, which is to develop a scientific attitude of students through practical and scientific activities [18]. According to Scientific Creativity Structure Model (SCSM) by Hu and Adey [19] science technical production is a key component of creativity in science. Science technical product refers to the artifact produced by the students based on the science concepts that they learned either in person or in group [19]. Creativity in science, better known as scientific creativity in teaching and learning science, is a understanding the concept of skills and use them to solve problems in science through creative ways [19-20].

Therefore, this study offers an approach to teaching and learning of physics through the integration of the five steps of engineering design (ask, imagine, plan, create, and improvement) with the five phases of Needham's constructivism (orientation, inducing ideas, restructuring ideas, application of ideas and reflections).

THEORETICAL FRAMEWORK

The engineering design is a problem solving activity through the development of an idea or product that requires creative thinking, in a systematic way [21-23]. Engineering design integrated in the teaching and learning is derived from the nine-step model of Accreditation Board for Engineering and Technology) (ABET) and has been converted into a five-step learning activities, namely; asking questions (ask), imagine, design (plan), create, and improvements (improve) [2, 9, 24-26]. To implement each step of the engineering design, students would be guided by the teachers namely on how to carry out every step of the engineering design effectively.

Adhering to the constructivist learning philosophy that learning is an active process, in which students construct their own meaning from the experience provided by the teacher. To ensure that students can build their own understanding through the five steps of engineering design, teachers were asked to carry out the teaching process in phases according to the theory of constructivism Needham, namely: phase of orientation, phase of generate idea, phase of restructuring ideas, phase of ideas, and phase reflection [27]. The five phases of Needham's constructivism model is subsequently used as a guideline or approach in assisting teaching and ensuring that students apply each step of the learning activities according to the five-step engineering design (ask, imagine, plan, create, and improve). Teachers through five phases of Needham's constructivism help and ensure that students carry out the five steps of engineering design as described below. Figure 1 shows a theoretical framework which forms the basis of this study.

RESEARCH OBJECTIVES

This study aimed to identify the effectiveness of teaching and learning module based on engineering design and five phases Needham's teaching constructivism in developing students' creativity through the development of science technical product among students. The research objectives of the study are:

1. To identify the level of creativity based on the developed science technical product after implementing the engineering design and five phases Needham's constructivism teaching and learning module.
2. To examine the impact of engineering design and five phases Needham's constructivism teaching and learning module on the students' creativity through the outcome of science technical product.

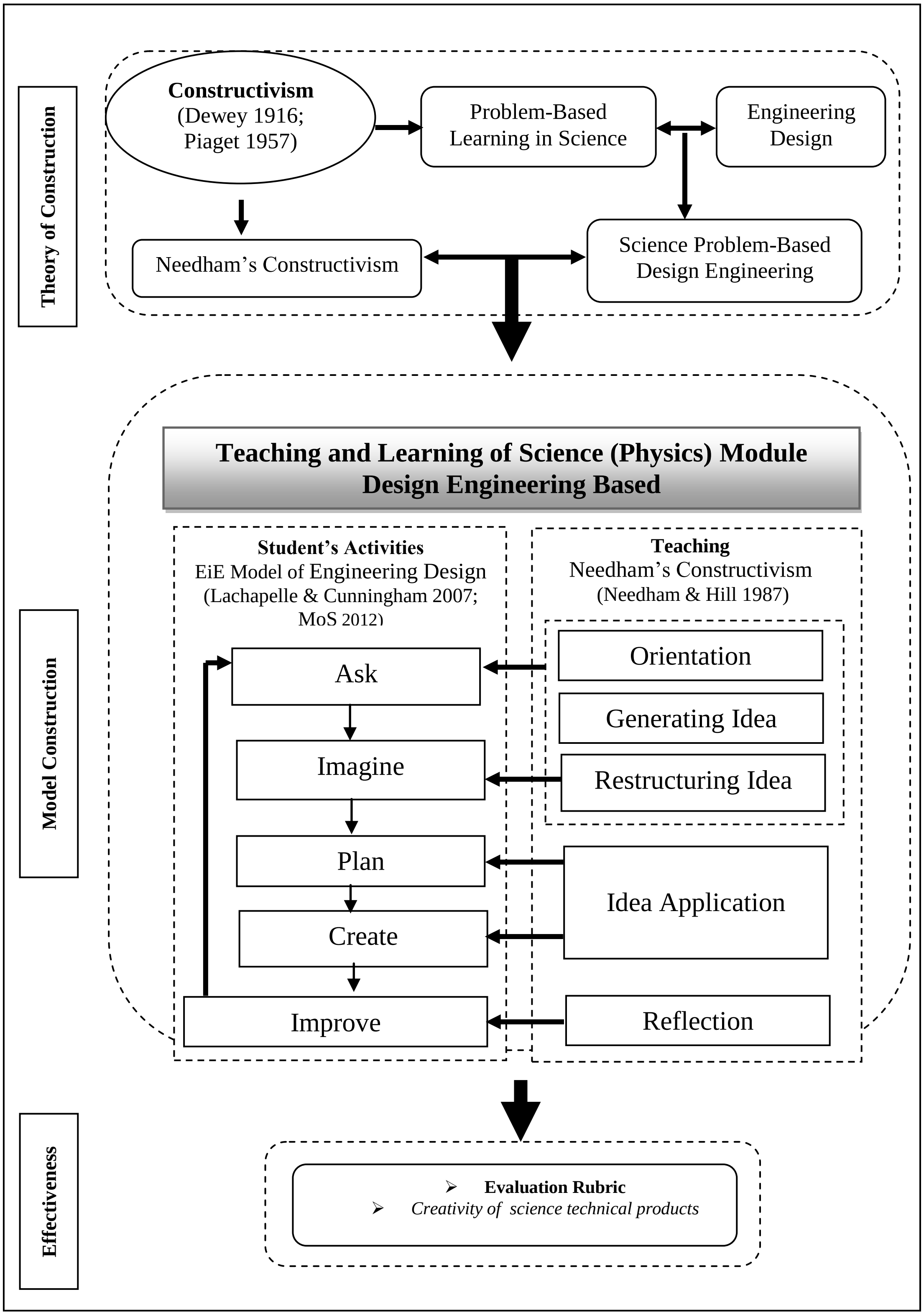

FIGURE 1. A conceptual framework of the study (adapted from [2,25,27,28])

METHODOLOGY

The research used a quasi- experimental research design with the integration of engineering design and constructivism in the teaching and learning of physics module. The populations in this study were students' Form three junior high schools in Aceh Besar, which carry out practical activities of laboratory physics theories and concepts they learn in the classroom. A total of 40 students had been selected. Two classes were randomly selected for the treatment and after twelve teaching and learning sessions, researchers carried out a science technical product evaluation as the output of the developed module.

The researcher used the product creativity assessment instrument of science to assess the level of creativity of science technical products produced by students after they followed all the processes from the module. The creativity of science technical product has been evaluated by four teachers who have been teaching electric and magnetic topics in form three junior high schools. Descriptive analysis of the level of creativity was conducted after students used the module. The level of creativity of science technical product is determined by creativity characteristics namely fluency, flexibility, unusualness, coherency, synthesis, simplicity, association, originality, elaboration, and value. The performance indicators of the creativity are divided into three stages that are low, medium, and high level of creativity. Table 1 shows the mean scores and interpretation of level of creativity based on technical products.

Physics teachers who assess students' creativity technical products also provide comments or views on the strengths, weaknesses, or even uniqueness of the products produced by the students. The various views of teachers on the technical products are taken as data supporting the assessment of technical products of the science student's creativities based on the ten characteristics of creativity. However, only the conclusions of the reviews are reported in this article.

TABLE (1). Mean Score level of creativity and interpretation of scientific technical products

Score Mean	Interpretation Level
1.00 – 1.66	Low
1.67 – 2.33	Middle
2.34 – 3.00	High

There are ten characteristics of creativity being evaluated from the technical product namely: fluency, flexibility, unusualness, coherency, synthesis, simplicity, association, originality, elaboration, and value. Briefly, the ten elements of creativity of science technical product according to Hu and Adey [19] and Lee *et al.* [29] are as follows:

i. Fluency - the number of idea or product produced
ii. Flexibility - the product can be developed and modified into a new category of ideas.
iii. Unusualness - the difference of idea or product produced as compared with an idea or conventional product.
iv. Coherency- idea or product that is produced with a scientific basis, logical, and consistent.
v. Synthesis- the number of ideas or items involved in the construction of unstructured and structured product

vi. Simplicity- the product is regularly good and simple.
vii. Association - similarity based on reasoning, meaning idea or product that is produced has a relationship with an idea or product that is based on equality.
viii. Originality- a new idea or product that is not yet created by others.
ix. Elaboration - the idea or product that is produced is complete and in detail.
x. Value- idea or a new product developed is useful to society, environment, and also can solve the problem.

ACTIVITIES

Generally, the activity aided teaching and learning physics module during a 12-week study session is as shown in Table 2.

TABLE (2). Activities in the teaching and learning modules

Week	Teaching and Learning Activities
	Ask
1	Physics problems "Free Electricity" SW 1, & SW 2
2	Concept of Electric Static & SW 3
3	Concept of Dynamic Electric & SW 4
4	Concept of Magnet & SW 5
6	Electromagnetic concept & SW 6
8	The concept of Electromagnetic Induction & SW 7
	Imagine
5	Hands-on activity 1 (Characteristic of Electricity & Magnetism)
7	Hands-on activity 2 (Magnetism from Electricity)
9	Hands-on activity 3 (Electricity from Magnetism)
10	**Plan**
11	**Create**
12	**Improve**

*****SW=Student Worksheet

FINDINGS & DISCUSSION

The descriptive analysis of the level of creativity based on science technical products generally described by the mean and standard deviation as shown in Table 3. Based on Table 3, it was found that the mean score of the science technical product creativity as a whole is at 1.90 and a standard deviation is 0.40. According to the mean scores, the level of creativity as a whole can be interpreted at a moderate level, with a 12 (30%) of students at a low level, 16 (40%) at a moderate level, and 12 (30%) at a high level. The mean and standard deviation for each product reflect the elements of creativity demonstrated by the students from the science technical product they developed - fluency, unusualness, originality, association, elaboration, flexibility, coherency, synthesis, simplicity, association, value and originality. This finding indicates that the five-step integration of engineering design and five phases of Needham's constructivism in science teaching and learning module are capable of forming and developing students' ability in demonstrating creativity elements through the production of a science technical product.

TABLE (3). Mean, standard deviation, and number/ percentage of level of creativity based on science technical products

Features of Product Technical Sciences	Mean	S.D	Level of Creativity based on Science Technical Products		
			Low	Medium	High
Fluency	1.89	0.60	12 (30%)	16 (40%)	12 (30%)
Flexibility	2.00	0.30	-	34 (85%)	6 (15%)
Unusualness	1.69	0.43	22 (55%)	18 (45%)	-
Coherency	1.90	0.43	12 (30%)	22 (55%)	6 (15%)
Synthesis	2.00	0.50	12 (30%)	16 (40%)	12 (30%)
Simplicity	2.07	0.40	6 (15%)	17 (42.5%)	17 (42.5%)
Association	1.91	0.48	18 (45%)	11 (27.5%)	11 (27.5%)
Originality	1.69	0.40	11 (27.5%)	29 (72.5%)	-
Elaboration	1.72	0.25	17 (42.5%)	23 (57.5%)	-
Value	2.15	0.67	11 (27.5%)	12 (30%)	17 (42.5%)
Total	**1.90**	**0.40**	**12 (30%)**	**16 (40%)**	**12 (30%)**

The teachers' assessment of the product demonstrated how students are able to demonstrate the 10 elements of creativity:

i. *Fluency features of science technical product*
The teachers concluded that overall the students were able to design successful science technical products that are able to solve the 'free electricity' concepts or problems? However, even though they have some new idea to produce new product but the teachers found that most of the students were not able to explain the relationship, the process of science and the application of concepts with effectively.

ii. *Flexibility features of science technical product*
The teachers concluded that the students have the flexibility element where one of them developed a product with complex technical science, although some students were not able to explain it.

iii. *Unusualness features of science technical product*
The teachers viewed that students provided modification of ideas that are different with other technical products.

iv. *Coherency features of science technical product*
For coherency features, the teachers found that students have managed to grasp the concept of electricity and magnetism well and can apply them to a science technical product as a solution to a problem on a topic of "free electricity".

v. *Synthesis features of science technical product*
In general, the teachers stated that for synthesis feature of creativity in science technical products, it was found that the students were able to apply what they drafted and planned into a product. They were also able to explain the steps while designing a product systematically.

vi. Simplicity features of science technical product
The teachers generally viewed that technical products of science students was simple, which are the tools and materials used are easy to find and not too complex.

vii. *Association features of science technical product*
To characterize this association, the teachers concluded that the science technical product has met the criteria of the association - which can be used to solve more complex physics problems related to the topic of "free electricity".

viii. Originality features of science technical product
The teachers stated that some students was able to design and build science technical products through the ideas of their own even though they are not able to explain the uniqueness and differences with other groups.

ix. *Elaboration features of science technical product*
The teachers generally stated that students were able to explain each section in detailed of the technical product, but they were still not able to link between the parts integratedly.

x. *Value features of science technical product*
For this feature, the teachers who assessed the science technical product viewed that the students have succeeded in designing science technical products that has value to the environment and society. E.g., they utilized a fan that an equipment that is environmental and electrical friendly.

In general, the science technical products produced by students are still at the stage of modifying existing products, thus the resulting technical product science of the students is not very significantly different. However, some students were found to have been able to produce a technical product that is simple, neat and can be used in everyday life, although in reality the product of the technical science still has many weaknesses and shortcomings. However, students were found to have an idea for improvement and it will become better if they are given more time and opportunity to fix it. Therefore, the findings of the level of creativity of science technical product showed that the use of the integration module design engineering and constructivism in the teaching and learning of physics has a positive impact on the scientific creativity of the physics student. Teachers and students also admit that this module was easy to used, helpful and facilitated their understanding to explain the concept systematically and in organized manner, trained to be more creative, and also had links to the everyday phenomenon.

CONCLUSION

The physics teaching and learning module was developed based on the five-step of engineering design (ask, imagine, plan, create, and improve) together with five phases of Needham's constructivism theory. The findings showed that the module gives students the opportunity to apply physics concepts they learned in the form of technical products in accordance with the understanding of science and creativity. The opportunity to apply this idea is less or even not obtained by students by using traditional text book where students are instructed to carry out practical activities and hands-on to confirm the results that already expected and predetermined. This is because the approach implemented in the teaching and learning of conventional physics only to strengthen students' conceptual understanding of physics alone. Teacher needs new approaches of teaching physics to cultivate creative and innovative thinking. Therefore, it is fitting for us to focus more on teaching and learning approach that allows students to be more active, creative, and innovative approaches such as methods that have been implemented in this study.

As a conclusion, this study found that the modules are constructed in a planned and systematic approach based on the five-step design engineering (engineering design process) and teaching model with Needham's five phases constructivism has managed to generate creative science technical products among student. This finding suggests that module construction in a planned and systematic approach and appropriate teaching model has a very positive effect on the creativity of students.

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