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Effects of the Science, Technology, Engineering, and Mathematics (STEM) Activities Related to Mitosis Topic on Academic Achievement and Engineering Design Ability

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Abstract

Science, technology, engineering, and mathematics (STEM) education can help students having knowledge and understanding for using in their daily life. Organization of STEM activities based on inquiry-based learning are teaching methods which can help students understand scientific concepts and engineering design ability. This study was aimed to compare academic achievement and engineering design ability of grade 10 students who learned by using STEM activities based on inquiry-based learning. The sample use in this study consisted of 29 grade 10 students in science-mathematics major of Benchamarachuthit Chanthaburi School, Thailand. The research instrument used in this study were (i) STEM activities based on inquiry-based learning lesson plan in the topic mitosis, (ii) an academic achievement in the topic mitosis test with difficulties (P) ranging 0.32 – 0.65, discriminating power ranging 0.35 – 0.76 and a reliability of 0.87, and (iii) an engineering design ability test with difficulties (P) ranging from 0.46 – 0.67 with discriminating power of 0.39 – 0.72 and reliability of 0.81. Results showed that the STEM activities based on inquiry-based learning lesson plan had effective criterion 81.55/90.66. Effectiveness index of STEM activities based on inquiry-based learning was 0.85. The posttest scores of academic achievement and engineering design ability test were significantly higher than those pretest scores ($p < .05$). Therefore, the instructor could implement this teaching method for learners to achieve their learning outcomes in the future.

Keywords: STEM education, inquiry-based learning, Academic Achievement, Engineering Design Ability

Introduction

Due to the national economy, more engineers and skilled workers in science, technology, and mathematics fields who also possess competencies in critical thinking, communication, and collaboration are needed (Faber et al., 2013). In many countries including Thailand, there has been an increasing emphasis on improving science education, therefore, science teachers have been calling to integrate science and engineering practices into science teaching. Therefore, the new educational approach has appeared with the addition of engineering in the discipline of science, technology, and mathematics called as the STEM. Many scholars claimed that the integration STEM education is beneficial to the economy (Tseng et al., 2013).

STEM education is an interdisciplinary instruction that integrates science, technology, engineering, and mathematics to solve real-life problems professional processes (Bybee, 2010). It offers learners one of the best opportunities to experience learning in a real-world situation, rather than to learn bits and pieces and then to have to assimilate them at later time (Shahali et al., 2017). The concept of STEM education was introduced in Thailand around 2012, and the implementation of STEM education is now required. STEM education research in Thailand is increased for many years. Many researchers conducted STEM education into science subject (Promboon, Finley and Kaweekijmanee, 2018).

In science subject, the method allows students' learning by doing how to solve problems by themselves is an inquiry-based learning. (Dewey, 1983; Nuangchalerm and Thammasena, 2009). Inquiry-based learning can be mentioned to several ways in which study the natural world and it consisted of the activities of students in which the develop knowledge and understanding of scientific concepts (National Research Council, 1996). Therefore, science teaching needs to be able students having knowledge and understanding of scientific concepts. Inquiry-based learning should help students meet real science through the activities (Nuangchalerm and Thammasena, 2009).

Engineering design process has been recognized as one of the crucial parts of STEM education (Lin et al., 2018). It can encourage students learning of the mathematics and science concepts that make technology possible (Shahali et al., 2017). Atman et al. reported that engineering design activities can help students gain insights into their own design process and develop students engineering competencies. Moreover, the students conceptual understanding and creative thinking can be developed by engineering design process (Atman et al., 2007).

Cell division is the part of Biology concept, it is the basis for many topics such as genetics, reproduction, and molecular biology subjects. (Oztas et al., 2003). Many researchers founded that the students have many conceptional problems concerning cell biology and genetics (Flores et al., 2003). There are a number of strategies used to develop students' concept of cell division. To exemplify, Çalik and Ürey mentioned that since students' understandings are not completely remedied by means of only one conceptual change method (Ürey & Çalik, 2008). The instructor should be using different conceptual methods embedded within the 5E model will not only be more effective in enhancing students' conceptual understanding, but also may eliminate all students' misconceptions.

This study aimed to compare academic achievement and engineering design ability of grade 10 students who learned by using organization of STEM activities based on inquiry-based learning. The results of this study can enhance students meet conceptual understanding and engineering design ability.

Research methodology

In the present research, a semi-experimental model with one-group pretest and posttest design was used. During the application step of the research, the topic of mitosis was taught using STEM activities based on inquiry-based learning. STEM activities based on inquiry-based learning constitute the independent variables of the research, and academic achievement and engineering design ability the dependent variable. The research was carried on in 2020 academic year.

Participants

The participants were grade 10 students of Benchamarachuthit Chanthaburi School, Chanthaburi, Thailand and sampling group was chosen using a purposive sampling approach. The sample was 29 students studying in grade 10 in science-mathematics major of Benchamarachuthit Chanthaburi School.

Research instruments

In the research, "academic achievement in the topic Mitosis" and "engineering design ability test were used to determine the effects of STEM activities on academic achievement and engineering design ability.

1. Academic achievement test

A two-tier diagnostic academic achievement test was developed by the researcher. There are 6 items in the topic mitosis of grade 10 student. The values of the difficulty index, discrimination index, and reliability indicated that all the items in the academic achievement test were proven to be applicable.

2. Engineering design ability test

The engineering design ability test was developed by the researcher. There are 20 items includes five phase of engineering design process (problem scoping, idea generation, design and construct, design evaluation, and redesign) English and King (2015). The values of the difficulty index, discrimination index, and reliability indicated that all the items in the academic achievement test were proven to be applicable.

Research procedure

The application was carried out during the course hours in the normal course schedules for the biology on second semester. The STEM activities lesson plan was used in compliance based on inquiry-based learning. The example of STEM activities as follow;

Mitosis activities

Step 1 Learners are engaged by scientifically oriented questions.

- In this phase, A case study questions are presented to the students in order to make them discuss with each other, then students were ark to share their thoughts about the cell division to determine their prior knowledge and encourage them to engage in learning the topic.

Step 2 Learners give priority to evidence.

- In this phase, the students were separated groups of 5 or fewer.

- Students were asked to arrange the photo of mitosis between the photo by drawing and under the microscope. They were allowed to use the source textbook and the internet on their devices. (Figure 1)

Figure 1 Students were asked to arrange the photo of the mitosis.

- Then, students were asked questions that promoted their knowledge about the subject and created a discussion, follow by;

1. What is the type of cell division in the photo that you have arranged and is it important?
2. What is happened in the process of mitosis
3. What are the result?

- After that, the teacher asked each group of students to create the model of mitosis. the work sheets of engineering design process prepared for each group were given. They were made the model by using an inexpensive material. The model produce should be good, and useful to teach on the topic cell division.

- Each group were made the model follow by 5 steps of engineering design process (1. Problem scoping, 2. Idea generation, 3. Design and construct, 4. Design evaluation and 5. Redesign) English and King (2015). they could ask the teacher for help if they considered it necessary. (Figure 2)

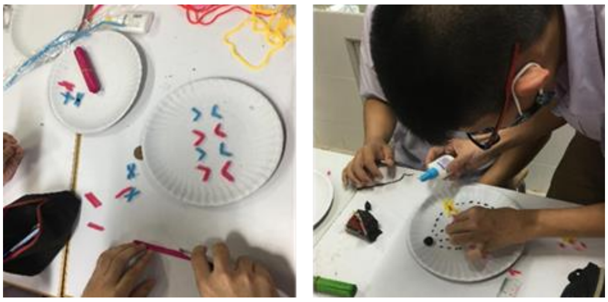

Figure 2 Students create their model.

Step 3 Learners formulate explanations from evidence to address scientifically oriented questions.

- After each group were finished the model. The groups then chose a spokesperson to report their model to other groups. They were discussed each other. (Figure 3)

- Then, the work sheets of Mitosis prepared for each group were given. A response time of approximately 10-15 minutes was allowed for each question.

Figure 3 Students report their model to other groups.

Step 4 Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.

- The teacher summarized the topic of mitosis after the student' answers for each question on the work sheet.

Step 5 Learners communicate and justify their proposed explanations.

- Each group were asked to create a short video of mitosis by using "stop motion" application.

- Then, they were posted their short video on Facebook.

Data analysis and statistics

1. The efficiency (E1/E2) and effectiveness (E.I.) of STEM education approach on mitosis topic.

- The percentage of the average of all scores the students earn from their activities is calculated to represent E1. And the percentage of the average of all scores the students earn from their posttest is calculated to represent E2 (Brahmawong, 1998).

- The effectiveness index (E.I.) is calculated by using the data from pretest and posttest scores. The E.I. is thus computed as follows:

$$E.I. = [(P2 - P1) / (100-P1)] * 100$$

E.I. = The effectiveness index
P1 = Pretest score
P2 = Posttest score

2. The academic achievement score.

- Mean, percentage, and standard deviation of pretest and posttest scores are calculated.

- The score of pretest and posttest are analyzed with a t-test for dependent samples.

- The normalized gain <g> of the pretest and posttest are analyzed and divided into 3 levels (Hake, 1998).

3. The engineering design ability score.

- Mean, percentage, and standard deviation of pretest and posttest scores are calculated.

- The percentage scores of the engineering design competency from pretest and posttest are distributed frequently into 4 levels adapted by Sangkharak and colleagues (Sangkharak et al., 2017) presented in Table 2.

Table 2 The criterion of the engineering design ability

Range of scores	levels
80 - 100	excellent
50 - 79	good
20 - 49	moderately
0 - 19	low

- The score of pretest and posttest are analyzed with a t-test for dependent samples.

Results and Discussion

1. The efficiency (E1/E2) and effectiveness (E.I.) of STEM education approach on the mitosis topic.

- The result of the efficiency E1/E2 was 81.55/90.66 that higher than the criteria of 80/80 that was following the purposed since the process of developing the STEM activities was excellent.

- The result of the effectiveness index (E.I.) was 0.85 that higher than the criteria.

- The normalized gain of the students in the experimental group was calculated following Hake (1998). Analysis results are given Figure 4.

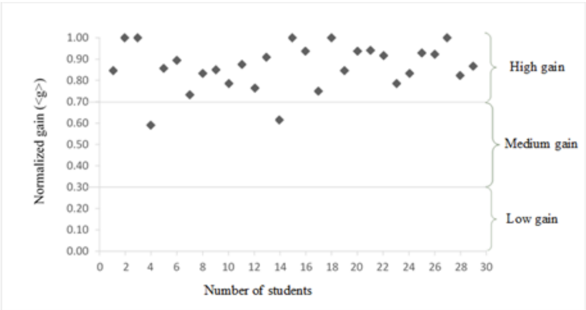

Figure 4 Normalized gain index of the mitosis academic achievement in individual students results.

According to Figure 1, there was a normalized gain index of the scores obtained from the pretest and the posttest students mitosis achievement test (0.85, high gain). According to this result, these activities were more successful for the students.

2. The academic achievement score result.

Before the start of the activities. The pretest percentage score of the experimental group student was 35.92 (fail level). After they have learned by these activities, the posttest percentage score of the experimental group student was 90.66 (excellent level). The result of the analysis is given in Figure 5.

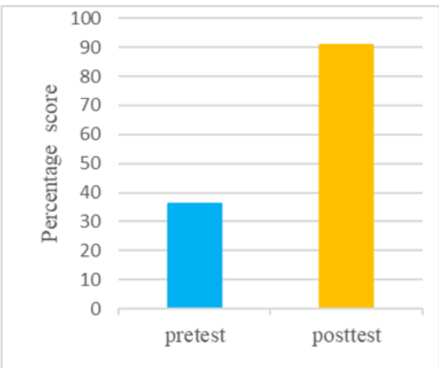

Figure 5 The percentage score of pretest and posttest of academic achievement

The significance of the mean score difference between the pretest and posttest scores was calculated by independent t-test. The result of the analysis is given in Table 3.

Table 3 Analysis of dependent t-test regrading students' academic achievement test.

	n	$\bar{x}$	S.D.	t	p	df
pretest	29	4.31	1.14	22.411	.000	28
posttest	29	10.74	1.78			

p> .05

According to Table 3, there was a statistically significant difference between the experimental group students' pre- and post-application academic achievement (t = 22.411, p <.05). The average of academic achievement scores of the experimental group students before the application was $\bar{X}$=4.31, increasing to $\bar{X}$=10.74 after application. This finding showed that STEM activities in mitosis topic have a significant difference on students' academic achievement.

According to the results, the academic achievement of mitosis subjects in experimental group had increased statistically. The detail of mitosis in the STEM activities covered the scope of Thai science course in high school. At the pretest the academic success average of the experimental group was lower, but after the application the experimental group was more successful of posttest because the STEM activities were integrated the knowledge of mitosis (science) with technology, engineering and mathematics. This result suggests that inquiry-based STEM education significantly increases academic achievement. This result also relevant research findings that reported STEM increased academic achievement. Buyukdede and Tanel have reported that STEM on the work-energy topic had a positive effect on academic achievement (Büyükdede & Tanel, 2019). In addition, Cevik has found that student had improved their academic achievement after they have learned by STEM education (Çevik, 2018). In addition, another research has shown that STEM education helped students with low academic abilities had the highest mean gain (Yaki et al., 2019).

3. The Engineering design ability score result.

Before the start of the application. The pretest percentage score of the experimental group student was 49.14 (moderately level). After they have learned by these activities, the posttest percentage score of the experimental group student was 97.41 (excellent level). The result of the analysis is given in Figure 6.

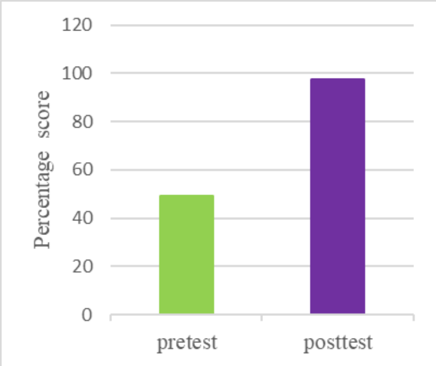

Figure 6 The percentage score of pretest and posttest of engineering design ability.

The significance of the mean score difference between the pretest and posttest scores was calculated by independent t-test. The result of the analysis is given in Table 4.

Table 4 Analysis of dependent t-test regrading students' academic achievement test.

	n	$\bar{x}$	S.D.	t	p	df
pretest	29	9.82	0.74	30.655	.000	28
posttest	29	19.48	1.54			

According to Table 4, there was a statistically significant difference between the experimental group students' pre- and post-application engineering design ability ($t = 30.655$, $p < .05$). The average of engineering design ability scores of the experimental group students before the application was $\bar{X} = 9.82$, increasing to $\bar{X} = 19.48$ after application. This finding showed that STEM activities in mitosis topic have a significant difference on students' engineering design ability.

According to the results, the engineering design ability in experimental group had increased statistically. The students can be enhanced engineering design ability because they have learned the process of engineering design through the activities in mitosis topic. therefore, they have developed their engineering design ability. At the pretest, the engineering design ability average of the experimental group was moderately, but after the application, the experimental group was more successful in posttest because the STEM activities were emphasized the process of engineering design, as follows. In the problem scoping, the students can define the problem on the model of mitosis in their class. In this phase, they were establishing brainstorm in their group. At the idea generation phase, they were shared the idea for developing the new model in mitosis topic. Then, they were developing a plan to make it. In the design and construct, the group of students were sketched the mitosis model. Then, they were transformed their design to a new model. Next phase, the design evaluation. They were testing their model. During this phase, the groups then chose a spokesperson to report the new model of mitosis to other groups. The teacher and other groups were evaluating the mitosis model in the materials, worthiness, correctness of the model. In the redesign phase, the groups were clarifying the imitation of their model, in order to enhance the new model, they were sketching a new design for improving the mitosis model from the suggestion of the teacher and other groups.

This result suggests that inquiry-based STEM education significantly increases engineering design ability. This result also relevant research findings that reported STEM increased engineering design ability. Sangkharak and colleagues have reported that STEM education learning can promote the engineering design ability (Sangkharak et al., 2017). The students who have learned by STEM education were at excellent level of engineering design ability. Also, English and King (2015) have founded the student can apply the STEM education knowledge to design and construct the aerospace. The engineering design were developed after they have learned with STEM learning through engineering design.

Conclusion

In conclusion, this study emphasized on the using STEM activities based on inquiry-based learning to enhance student academic achievement and engineering design ability.

The academic achievement score of grade 10 students was higher than those before implementing and the engineering design ability was also higher than those before implementing.

The result indicated that this method can promote academic achievement and engineering design ability development, also learning satisfaction of students were responded at high level. Therefore, the instructor could implement this teaching method for learner to achieve in the future.

Conflict of Interest

The authors have no conflicts of interest to declare.

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