Learning management through engineering design process based on STEM education for developing creative thinking in equilibrium topic for 10th grade students

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Abstract Nowadays, the economy is highly competitive, the government needs to develop innovations to increase the value of output by focusing on using creative thinking and innovation to solve the problem. The purpose of this research was to develop creative thinking through engineering design process based on STEM education in the topic of equilibrium for 10th grade Thai students. The methodology of this research was classroom action research. The participants were 44 students. The research instruments included students’ worksheets, posters and student’s artifacts, classroom observation forms and interviews. The data were analyzed using content analysis. The results of this study illustrated that the learning management through engineering design process based on STEM education can promoted students’ creative thinking in the following three competencies, in order of the number of students showing development from most to least: 1) Implement Innovations; 2) Work Creatively with Others; and 3) Think Creatively.

1. Introduction
One of the purposes of the 21st century education is to develop the students to prepare for knowledge and ability in various skills and make them to be creative individuals. Students will face the situations that challenge them to produce creative ideas in order to solve problems in their daily life [1]. Creative thinking is operationally defined as think creatively, work creatively with others, and implement innovations [2]. The world has become more complex in present day, the decision makers face environments in which things that were isolated from one another just 30 years ago are bumping up against each other, often with unexpected results [3]. Problem solving with traditional method is not enough to solve these new challenges effectively [4]. In order to solve problems and exploit opportunities, it is necessary to think creatively and find useful and original ideas. According to survey, creativity is an integral part of modern work. Not just for arch-strategists or chief executives, but for all of us [5,6]. In addition, creative thinking is an essential factor for the discovery in science. Scientists use their creative thinking to generate new solutions or laws by using the knowledge [7]. In science classroom, students need to use creative thinking to find solutions that lead to invent and create new innovation [2].
People’s creativity level over the past decades was decrease [7,8]. People are less open to new experiences and different people, ideas, and views. Research reported that creativity was decreasing in the USA across all age groups. The declining of creative thinking were shown from children becoming less imaginative and verbally expressive, lack to analyze information and motivates to elaborate ideas and details [7]. In Thailand, the government has launched a new policy “Thailand 4.0” in 2016 in order to marks the significant change of the country’s economy into value-based economy or innovative driven economy. It focuses on technology, creative thinking and service sector in order to add values and services [9]. However, several studies found that Thai students still do not have creative thinking [10,11]. It can be seen from student usually remember the knowledge that relate to lesson [10]. Student cannot create and offer their own ideas for make solution [11]. To understand creative thinking of Thai students in depth, the researcher of this study investigated students’ creative thinking during force and motion lesson through field note. The result revealed that most students could not create solution to solve problems that they had never seen before even though the problems were related to their science content background. They usually asked the teacher to tell the solutions of the problems or copied solutions from their classmates.

STEM education is an approach that encourages students to integrate concepts among four subjects including science, technology, engineering, and mathematic and it emphasizes the application these disciplines for solving problems in their daily lives and preparing them for future careers [12,13]. STEM education becomes popular across the world including in Thailand. Institute for the Promotion of Teaching Science and Technology (IPST) was the first organization that introduced the STEM approach to Thai science teachers in 2016 in order to achieve to the policy “Thailand 4.0”. The learning management through engineering design process is the main teaching method that was introduced by IPST. This process provides students with an opportunity to systematically design their solution and apply that solution to new situations under the conditions that related into real-world [13,14]. It also helps to develop thinking skill and conceptual understanding about science, mathematics, and technology. Through this process, students were developed to have an engineer behavior and creative thinking that are one of six important engineer’s behavior and use engineer process in their daily life [14]. The integrative STEM approach using engineering design practices has a potential to improve higher-order thinking skills [15].

Therefore, the purpose of this study was to develop creative thinking through engineering design process based on STEM education in the topic of equilibrium.

2. Method
This study employed an action research, which consists of four steps including plan, action, observation, and reflection. There were three cycles of action research in this study, which covered three concepts comprising of static equilibrium, rotation equilibrium, and equilibrium in daily lives respectively. Each cycle lasted around 4 hours.

2.1. Participants
The participants in this study were selected by purposive sampling. They were 44 tenth grade students in science-math program. All participants were female who enrolled in physics subject in 2017 academic year. Most students were familiar with traditional style of teaching in science classroom including lecture and demonstration. All students had smart phones with internet connection. None of students ever had experience with STEM lessons prior to this study. The physics classroom in this study is a laboratory room. This room has a table for group work, which the students can move or adjust to suit their learning activity. There are free Wi-Fi available for all students that provided by the school.

2.2. Learning management through engineering design process based on STEM education
This study used the steps of engineering design process in developing three STEM lessons in topic of equilibrium. This learning management through Engineer design process has steps as follow; 1) Problem identification; students required to understand and identified limits and conditions of situation.
2) Related information search; students must to investigate and compile knowledge that related to situation. 3) Solution design; this process, students will use their information from previous step to create ideas and finding the solution of situation. 4) Planning and development; students will take the ideas and solution to planning and creating a prototype. 5) Testing, evaluation and design improvement; this step students will test their artifact to finding mistakes for development and improvement. 6) Presentation; students are present their result of activity [12]. This learning management was required students to make the model according to conditions of each situation by using engineering design process. The situations in each cycle of action research were different depending on concepts. In the first cycle, the students were required to make the highest tower from 20 straws and plasticine in order to stand by itself for at least one minute. In the second cycle, the students were required to make a bridge from straws and tape under limited budget in order to carry weight as much as possible. In the third cycle, the students were required to make a machine for sending the ball from one place to another place in range of five meters within two minutes by using a corrugated plastic sheet and five meters of rope. The first author of this research article was an instructor in all three learning cycles.

2.3. Research instrument
The research instruments that were used to explore student’s creative thinking in this study consisted of students’ worksheet, students’ model, posters, and classroom observation forms. Creative thinking in this study comprised of three components: think creatively, work creatively with others, and implement innovations. The details of each instrument were described as follows.

Students’ worksheet was used to investigate the think creatively and work creatively with others components. The main parts of a worksheet were members’ name, conditions of situation, related knowledge, plan and procedure, blueprint model, result of testing, problem, cause of problem and problem solving, and suggestion [12]. Each group had to complete the worksheet during each activity of each cycle and sent to the researcher at the end of each cycle.

Students’ model was used to investigate implement innovations component. The model that the student constructed was used as complementary activities according to the conditions of each situation for assess students’ applying knowledge. Students had to create a model as group work by using engineering design process. Three models that they were assigned to construct consisted of the highest tower, the straws bridge, and take me away. Each group had to send their model to the researcher after at the learning each cycle.

Posters was used to investigate think creatively components. The main parts of a poster were situation’s condition, related knowledge, solution and planning, problems, prototype and development, model’s assessment, and suggestion.

Classroom observation form was used to observe student behaviour in classroom that related to the components of creative thinking during an activity. It was used to investigate all components of creative thinking. The main components of observation form were students’ behavior in aspects of identify problem, compile knowledge, plan and design, creation, prototype and testing, and assessing model. The observation form was used during learning activity by first researcher.

2.4. Data collection and data analysis
The first author of this study was an instructor of all three STEM lessons using engineering design process. During instruction of each cycle of action research, each group of students were asked to complete students’ worksheet at every steps of this instruction. Each group would construct a model in step planning and development and then they had to create a poster in step presentation of this instruction. The students had to send worksheet, a model and a poster at the end of each cycle. The researcher used classroom observation form during instruction of all three cycles.

Data from all research instruments were analysed through content analysis in order to reflect creative thinking of the students in all three components: think creatively, work creatively with others and implement innovations.
3. Result and discussion
The result of this study would be presented in three main parts according to the main components of creative thinking consisting of think creatively, work creatively with others, and implement innovations.

3.1. Think creatively
The student who can think creatively should be able to use process or techniques of idea creation to complied knowledge for creating solutions, create new ideas that reliable and actual availability to make an artifact, and examine, analyze and evaluate their own ideas in order to improve and develop creative ideas. The results of this part were analyzed from students’ worksheets, classroom observation form, and poster.

The result of cycle one revealed that students could comply knowledge for making the solution to solving problem but it was not exactly. One-thirds of students could write the knowledge that related to activity such as the center of mass and center of gravity. However, two-thirds of students wrote irrelevant knowledge during constructing the tower such as art for make a beautiful tower (data form students’ worksheet and poster). Students could not create the new ideas to make their artifact. For example, three-tenths groups of students were surfing the internet in order to find the straws tower models. Then, they copied that model to create a prototype (data from students’ worksheet and classroom observation form).

The result of cycle two revealed that students used the idea creation techniques to assemble related knowledge and data for doing an activity. Every group of students did brainstorming during related information search step. They talked with their groupmates and offered to use knowledge about rotational equilibrium. Then other students suggested that it also involved with moment of force in order to bridge stabilize (data from classroom observation form). However, there were four group of students that could not cooperate with their groupmates. They only worked on their part and not participated in their group discussion (data from classroom observation form). Students could not verify their suggested ideas as they ignored to check their groupmates ideas. Therefore, their group ideas were not various (data from students’ worksheet and classroom observation form).

The result of cycle three revealed that students had progression in model creating ideas. Every student in each group offered their own ideas to develop a transport machine. It could be seen that every student in a group helped to think how to make and analyze the possibility to build the model (data from classroom observation form). It was similar to when teacher asked the students, “How do you create your model?” Students said, “First, they would create the machine with a square of corrugated plastic sheet and then make a wall around the center in order to place the balls and tied a rope in four corners. But one of them thought that it might be hard to transport the ball and she suggested their group to make a hole in the center of plastic sheet for place the ball in there.” (data from classroom observation form).

The results from data analysis in three cycles indicate that students could compile knowledge in order to make the solution that lead to create their model by using idea creation techniques. They could analyze and evaluate their ideas that were suitable with the situation. In addition, students had progression in idea creation from knowledge that they found and apply into their own ideas correspond with situation.

3.2. Work creatively with others
The student, who can work creatively with others, should be able to create new ideas and communicate others effectively, demonstrate originality and inventiveness to work with their colleague, be a good listener and give feedback, understand the limits and conditions in work to adopting new ideas, and learning from their mistakes and using cyclical process for develop their work. The results of this part were analyzed from students’ worksheets, model and classroom observation form.

The result of cycle one revealed that students could not create ideas and explain to others. Eight-tenths group of students had got the ideas from one or two students. Another student did not offer their own ideas and waited for their friends. Then, they judged the ideas by saying good or bad ideas (data from classroom observation form). Students could not express their own ideas to others. A quarter of
all students had to explain their own ideas twice or more by verbal and gesture (data from classroom observation form). Some of students did not understand the conditions of situation completely. It could be seen from the identifying the conditions to the situation by students. Half of them identified the condition about limits of equipment and time for making tower, but they forgot the condition that a tower needed to stand by itself at least one minute and should be as high as possible (data from students’ worksheet). Three student groups failed on the time condition. Their tower could not stand at least one minute. One group could not create the tower as their tower was collapsed before time measuring (data from students’ model).

The result of cycle two revealed that students had progression in identifying the conditions. All of students could identify conditions except two groups of students that they missed some conditions such as budget and time for creating their model (data from students’ worksheet). Students collaborated and assigned individuals’ duties, and when any members in their group had problems, other students helped to analyze problems and tried to find solutions together (data from classroom observation form). When someone offered the ideas, the other students analyzed and gave feedback to their friends’ ideas. Students used brainstorming to comply related knowledge, each student was surfing the internet and got some ideas for group discussion in order to judge, develop and apply the ideas into their work (data from classroom observation form). Students had to evaluate and develop their work. It could be seen from in the first testing of students’ prototype, the bridge could hold 140 grams of mass. In the second time, they improved their bridge by increasing the layer of bridge floor to make it stronger. From this development, the bridge could hold 280 grams of mass. The third time for their developing, they found the problem that the bridge was not long enough for carrying heavy mass, so they added triple length of bridge. Then, their bridge could hold 850 grams of mass (data from students’ worksheet and classroom observation form).

The result of cycle three revealed that all of students suggested the ideas for making the machine and gave feedback to their work in order to find the best solution. Everybody in group presented their own ideas for planning model and listed all of ideas to do their works. After that, they analyzed one by one idea and gave recommendation for applying the ideas into their work (data from classroom observation form). Students could demonstrate their inventiveness and benefit for each parts of machine. In planning and development step, students designed a model and drew a blueprint in their worksheet. The blueprint, which students made, had the explanation of every part. For example, students explained that this part is a wall for preventing the ball to fall and it was made from cutting three side of corrugated plastic sheet in rectangle shape in order to make wall as following process: drilled a small hole on the top of each rectangle, inserted the rope to the hole and bided the rope to next edge of wall. (data from students’ worksheets).

The results from data analysis of three cycles showed that the students understood and could identify the conditions of situation. They could apply knowledge to use suitable for their work. Students had progression in describing their own ideas to others and gave feedback or recommend for develop their work. In addition, students could work with others and divided duties for the effectiveness of their work.

3.3. Implement innovations

The student who can implement innovations should be able to be applying the ideas that they create to make the innovation that tangible and useful. The results of this part were analyzed from students’ model and classroom observation form.

The result of cycle one revealed that students could create a prototype and improved their model but some students could not do according to the required conditions. Students constructed the tower from straws and plasticine. They were challenged to find how to construct the highest tower under the conditions; the tower must to stand by itself at least one minute. There were two student groups failed to make their towers stand at least one minute. However, there was one group of students failed to make the straws tower within required time. They tested their work three times but it was not high enough and when time was about to over, they were still making a base of tower. Finally, they could not create tower successfully (data from students’ model).
The result of cycle two revealed that students could make their model successful. Students required creating straws bridge to hold the most weight without breaking. Students tested and improved their work seriously because they wanted to be the winner and got the rewards (data from classroom observation form). The result of this activity was that every group could make the bridge that could hold the weight without breaking at least one minute. The winner group could create their bridge to hold 1,370 grams of weight and the last group, their bridge could hold 650 grams of weight (data from students’ model).

The results of cycle three revealed that students could apply their knowledge to create the model. In this cycle, students were required to make a machine for transport ball as much as possible within two minutes in range of five meter. Students planned and designed their work together. They discussed and applied their ideas that they found into their works for creating the best model (data from classroom observation form). In assessment of their models, all models from each group could work effectively. The winner group could transport 15 balls, while the highest group could transport 17 balls but when they poured ball into the bucket, three balls came out of the bucket. The lowest group could transport six balls because they had an accident during transport so, they could not pour the ball into the bucket as many as they expected (data from students’ model).

The results from data analysis in three cycles showed that students could apply their own ideas to make tangible and useful innovation by testing, evaluating, and improving their solution by learning from their mistakes.

4. Conclusion
The students developed their creative thinking continuously by using learning management through engineering design process based on STEM education. Students are required to show creative thinking behavior in order to identified problem, limits and condition of situation. In order to design solution, students need to refine and analyze their own ideas.

Acknowledgments
We would like to express our gratitude to Faculty of Education, Naresuan University and the Institute for the Promotion of Teaching Science and Technology (IPST) for providing scholarship for this research.

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