DEVELOPING STUDENTS' CREATIVE THINKING THROUGH STEM EDUCATION

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ABSTRACT

Developing students' capacity as well as good qualities is always one of the most important objectives of Vietnam's education; and creative thinking is likely one of the focus. The question here is how to organize learning and teaching activities to develop and foster learners' creative thinking. In this paper, by exploring different manifestations of creative thinking during the problem-solving process, the author proposes organizing a STEM-oriented project named as "I am an engineer" to develop students' creative thinking. This paper analyzes the organization of the project "I am an engineer" and its impact on students' creative thinking development; thereby, proposing a procedure to organize STEM-oriented projects and activities to develop students' creative thinking. The scores of the students' creative thinking were collected from three different sources including teacher's assessment checklist, students' self-assessment and peer review. Initial research results show that through teaching according to STEM education, students can develop self-reflection and creativity.

PHÁT TRIỂN TƯ DUY SÁNG TẠO CHO HỌC SINH THÔNG QUA GIÁO DỤC STEM

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Tư duy sáng tạo
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Dạy học Vật lí
Khoa học tự nhiên

TÓM TẮT

Một trong những mục tiêu quan trọng của giáo dục Việt Nam đó là phát triển các phẩm chất, năng lực của người học, trong đó có phát triển tư duy sáng tạo. Vấn đề đặt ra là: cần tổ chức các hoạt động giáo dục như thế nào để phát triển tư duy sáng tạo của học sinh? Dựa trên các giai đoạn của tiến trình giải quyết vấn đề trong quá trình học của học sinh, các biểu hiện của tư duy sáng tạo trong mỗi giai đoạn đó, nghiên cứu đề xuất tiến trình tổ chức hoạt động "Em là một kĩ sư" theo giáo dục STEM (gọi tắt là hoạt động STEM) nhằm phát triển tư duy sáng tạo của học sinh. Nghiên cứu sử dụng phương pháp điều tra thực tiễn và phương pháp thực nghiệm sư phạm. Nghiên cứu phân tích quá trình tổ chức hoạt động "em là một kĩ sư" và tác động của hoạt động đó tới sự phát triển tư duy sáng tạo của học sinh; từ đó, đề xuất tiến trình tổ chức hoạt động STEM nhằm phát triển tư duy sáng tạo của học sinh. Điểm đánh giá tư duy sáng tạo của mỗi học sinh được thu thập từ phiếu đánh gia của giáo viên, phiếu tự đánh giá và phiếu đánh giá đồng đẳng. Kết quả nghiên cứu bước đầu cho thấy, dạy học theo giáo dục STEM phát triển được tự suy sáng tạo của học sinh.

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1. Introduction

Creative thinking is identified as one of the most important high level thinking skills that the 21st century citizens need to acquire to live and work effectively in a global society. Creative thinking is a high-level thinking skill. People with creative thinking can not only analyze, identify and evaluate information or arguments from different sources but also think about their own thoughts. One of the most effective ways to achieve that is to bring learners into problem-solving activities.

Creativity refers to any human activity that creates something novel, regardless of whether it is concrete object, intellectual or emotional works belonging to human being [1]. A person possessing a creative mind is the one who has the manifestations of creating unique, revolutionary, and useful products [2]. The products can be tangible or simply the result or process of doing a certain job [3]. There are many approaches for an ordinary person and a student in particular to form and promote their creative thinking, such as gaining more practical experience, implementing more experiments, attending more discussions, etc. [4]. In order to develop the creative thinking for students in teaching, teachers need to generate an open learning environment where students can be freely creative and do the things they find most interesting [5], [6], [2]. Only when students feel unconfined, can their creativity be promoted at the highest level. STEM has been introduced to Vietnam for a long time and has received much more attention from educational researchers and administrators over the last few years. The new curriculum framework for general education in Vietnam (2018) which specifies the important role of STEM education and facilitating STEM education into general education is considered as implementing a basic change to the new educational framework. It is because demands of careers relating to STEM fields are constantly increasing and STEM education contributes to develop students' knowledge, skills, and competences to fit into the 21st human labor workforce. STEM education is then identified as an effective solution to the basic problem of developing students' creative thinking. Moreover, when engaging in STEM activities, students not only acquire knowledge of science but also develop various necessary competences besides creative thinking such as creative thinking and problem solving skills [1].

There are many different options to develop creative thinking of students [7], and STEM is the one of the most feasible educational activities to organize in high schools today [8]. One of the most outstanding advantages of STEM education is the connection of students' classroom knowledge with practical knowledge [8], [9]. Teaching and organizing educational activities can be through either STEM lessons [10], STEM experiences [11], [12] or STEM researches [12]. It can also be held either by high schools or classrooms themselves, or as a combination of high schools and educational research centers [9], [12].

Moreover, the current demand for jobs in industries related to STEM fields is increasing and the skills of workers in the 21st century also require a lot of related skills that STEM education can bring. Therefore, the application of STEM education in high school teaching in Vietnam in the current period is an indispensable requirement to meet the process of reforming programs and textbooks implemented from 2021 and meet the requirements of society. The question is how to organize STEM activities to develop students' creative thinking most effectively?

2. Methodology

2.1. Target group

To investigate the development of students' creative thinking through STEM activities, the research team conducted an exploratory research with a group of 10 high school students at Viet Bac Highland High School in Thai Nguyen province, Vietnam. Experimental actions were taken in the 2019/2020 academic year.

The research team initially expected to have more students participating in the empirical process so that the findings would be more convincing; however, there were a number of reasons affecting the sampling process as follows:

- On the one hand, Vietnamese students are currently under very high pressure of scoring good marks in formal learning activities and in all different kinds of tests around a school year. On the other hand, parents usually have high expectation on their children to have high academic achievement (grades), regardless of other factors such as their abilities to solve problems, develop creative thinking, and creative thinking. Therefore, it was very difficult for the team to invite the whole class of students to participate in the designed learning activities.

- Moreover, if a large number of students participated in the project at a specific time period, the team would have had other types of difficulties in tracking and evaluating the development of each student's thinking in general and creative thinking in particular.

Alternatively, the team conducted pedagogical experiments only with volunteering students after getting consent of the school' administrators and the students' parents.

2.2. Methods of Inquiry

Aiming at developing thinking competences for students especially their creative thinking, the research team made an initial assumption: STEM activity can develop learners' creative thinking. The team then developed a questionnaire that explored difficulties and levels of interest of students on STEM related contents. Based on the initial research findings, the team designed STEM activities and proposed the process of organizing these activities to develop students' creative thinking. Effectiveness of the activities would be measured based on creative thinking scales during the process students solved problems in the assigned tasks [1]. Data for the research was collected by using different techniques including a checklist, peer review, and self-assessment. The checklist was implemented accompanied by video recording all learning and discussing sections and the recordings were later viewed and analyzed carefully to retrieve information about the process of students' debating and thinking. Analyzing the process of students' thinking would help the researchers answer the questions: *Can the student's creative thinking be developed through STEM activities*? and *How STEM activities should be organized in order to maximize students' creative thinking development.*

3. Research Findings

3.1. Teaching practices and students' preference of STEM activities in Vietnamese high school

In order to understand and propose a process of organizing and selecting STEM contents integrated into high school curriculum, the research team retrieved data of a recent survey on current teaching practices that employ STEM activities and on students' interest in STEM activities at high school.

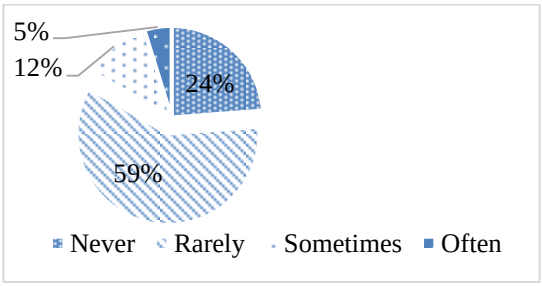

Figure 1. *Frequency of teachers' organization of STEM activities*

The survey was conducted by the research team from July 2019 to August 2020 with 42 teachers teaching science subjects and 442 students at 06 high schools including Thai Nguyen High School, Pho Yen High School, Chu Van An High School, Luong Ngoc Quyen High School, Phu Luong High School, Dai Tu High School located in Thai Nguyen and some other neighboring provinces. The survey results reveal information of STEM oriented teaching and students' level of interest in STEM oriented learning activities (Figure 1).

+ For the group of natural science teachers: In their teaching practices, the teachers had organized STEM activities, but the frequency was still low, the rate of regular use was also very low (5%). The reason for this is that the teacher must follow the instructional plan assigned by the school, while the STEM activities are quite time consuming for both the teachers and the learners. Another reason is that the assessment and evaluation process in Vietnamese classrooms seems not concern with competence assessment. To understand more deeply the causes of this situation, by directly communicating with teachers we also found that many teachers have not received specific guidance on designing STEM activities and they are also unclear about how students should be evaluated for this kind of activities.

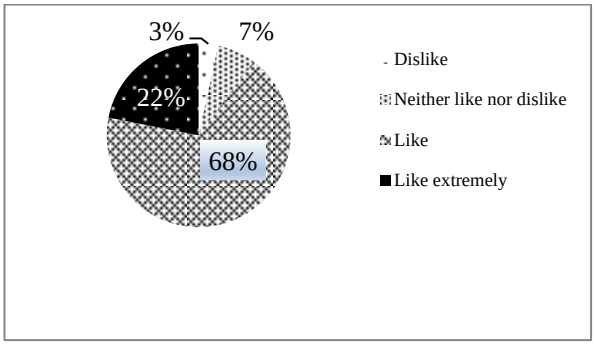

Figure 2. *Students' interest in STEM activities*

+ For students: During the learning process, they are easily engaged in observing scientific experiments and even more engaged in doing experiments by themselves. They also have very high interest in specific technical applications. They have many questions relevant to real-life situations. Most of the students showed preference for STEM oriented learning or STEM activities (90% of the respondents). This is a motivating factor and is also a favorable factor for the group to undertake the proposed pedagogical experiments into other stages of the research (Figure 2).

3.2. Manifestations of creative thinking during students' engagement in STEM activities

Creative thinking is a break with habitual patterns of thought. Creative insights often occur by making unusual connections, seeing analogies between ideas that have not previously been related. All of our existing ideas have creative possibilities. Creative insights occur when they are combined in unexpected ways or applied to questions or issues with which they are not normally associated [2]. Creativity is the ability to see things in a new way, to see problems that no one else may even realize exist, and even develop new, unique, and effective solutions to these problems. As Lipman emphasizes, it may illustrate many characteristics [3]. It should be original, but not purposeless or inappropriate [4]. The originality may offer a 'fresh' or even astonishing idea and it should be productive, resulting in valuable outcome(s). It should involve imagination that explores realms of possibilities. It should celebrate those who think independently and do not necessarily conform to others' views. It should involve searching and experimentation. It should be holistic, recognizing connections between part-whole and means-end relationships. It should be expressive in the way ideas are conveyed. It can be maieutic in nature, illustrating creative caring for others. It can be inventive, that is original, and offer potentially promising ideas, but it may not necessarily be practicable or immediately valuable. Various facets of creative thinking has been identified in the book *Developing Thinking, Developing Learning: A Guide to Thinking Skills in Education* [2] (see Figure 3).

Reviewing literature in the fields of investigating manifestations of creative thinking and problem-solving characteristics of STEM activities, our research team has identified basic manifestations of creative thinking during STEM activities including:

Criterion (1) Finding new problems: When confronted with a situation (maybe from an observation, from a class problem or from a situation), the students ask meaningful questions and this set a background for teaching creative thinking. Students' questions may be expressed in the form of questions like "Why?"; "What if ...?"; "Could it be .... for .... or not?"

Criterion (2) Proposing predictions: From observations, students base on their existing knowledge and experience to make predictions about relationships between quantities and/or provide explanations or description of the observed phenomena.

Criterion (3) Proposing solutions to the problems: Students undertake analyzing stage to develop 'initial' answers. These answers may provide solutions to the identified problems fully, partly, or not at all but it is required that the solutions are based on the existing knowledge.

Criterion (4) Implementing the solutions: From the proposed solutions that students create when just working with theoretical knowledge, they will turn the theoretical solutions to implementing actions. Sometimes the process of implementing solutions is quite simple that students do not need to show any sign of creativity. However, in some cases, in order to successfully implement the solutions, the students must deal with a range of related issues that require creative thinking.

Criterion (5) Improving selected solutions: In many cases, the solutions selected sound reasonable, but under specific practical conditions; for example due to bad weather conditions, economic circumstances, or lack of facilities; students cannot implement the proposed solutions. It then requires the students to perform the improvement of their solutions by which they become creative thinkers.

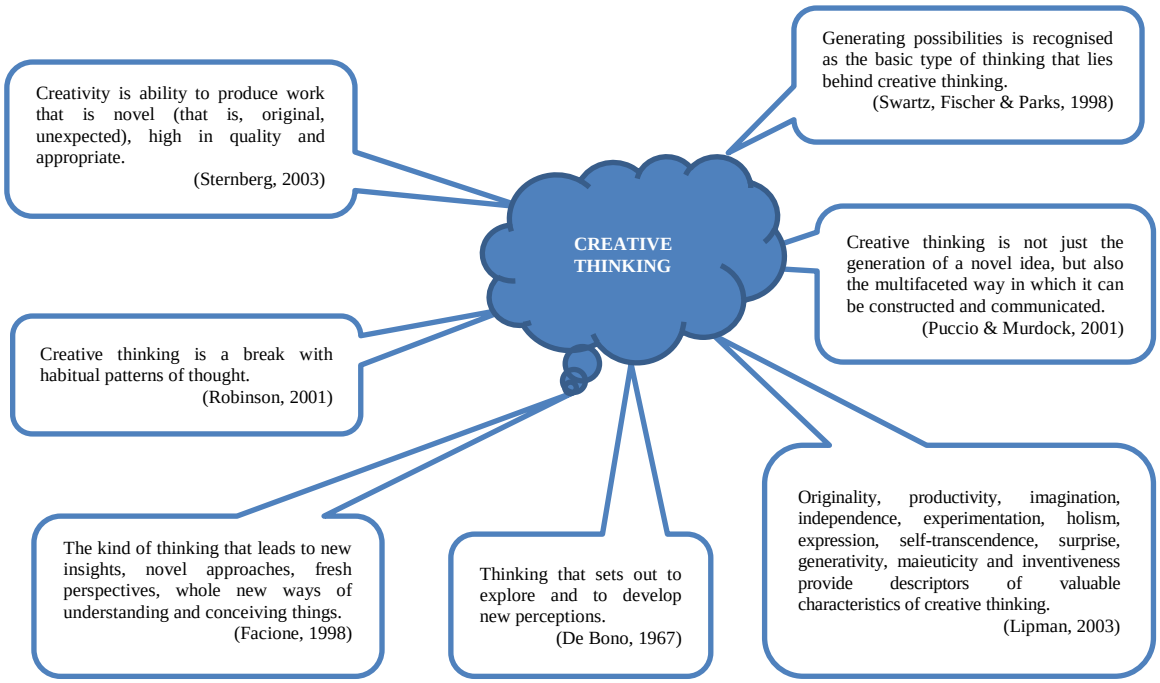

Figure 3. *Definitions of creative thinking* [2]

3.3. Stages of developing and fostering creative thinking during students' engagement in STEM activities

In order to develop and foster students' creative thinking, the teaching process needs to be organized so that students are facilitated to create creativity, arguments, and solutions to real world problems. Students are also given opportunities to implement their proposed solutions to

support their arguments [5], [9], [10]. Based on these assumptions, we adapted following five stages to implement STEM activities in Vietnam classrooms (see Figure 4).

Stage 1. Investigate practical problems: During this stage, the teacher offers a specific problem and asks students to solve it.

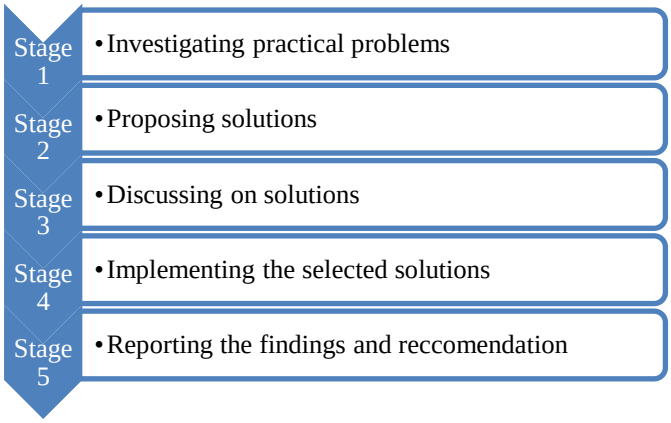

Figure 4. *Stages for implementing STEM activities*

At the beginning of the teaching section, the students' team looked at images and information about buildings that exceeded the permitted height that is a current controversial issue in Vietnam (This is real information that was once posted by a number of television and radio stations in Vietnam and attracted much attention from people). The teacher then facilitated students to probe questions about the possible problems (Figure 5). There were a number of questions been asked, some of them could be answered right away; however some of them required more time to process answers. The teacher then picked up a specific question about "How can people measure the height of buildings to see how many meters they exceed the height limit?" In this case, acting as an engineer, students will propose solutions and implement those solutions to determine the height of a particular building.

In 2007, the building No. 4 Dang Dung (Ba Dinh, Hanoi) was 23 stories high, 13 meters of which overpass

In 2007, the building 221-223 Bach Mai, Hai Ba Trung, Hanoi was built 15 meters over the permit

In 2009, building No. 34 Dai Co Viet, Hai Ba Trung, Hanoi was built over the 7.5m miracle

In 2015, the building of 8B Le Truc, Ba Dinh, and Ha Noi was the focus of the recent tumult - at the risk of being "cut off" the excess construction section of up to 16m

Figure 5. *Two of the images provided to students in Stage 1* [13]

The solutions recommended by the students participating in the experimental group reflect their current knowledge and experience. They are from the mountainous, remote, and isolated areas of Vietnam and have been studied at Viet Bac Highland High School - Thai Nguyen province.

As they live far away from home, they have to stay in the school dormitory. Taking advantage of this, the teacher specified task for students: determining the height of the dormitory where they live.

Stage 2. Proposing solutions: From the assigned tasks, students discussed to propose solutions to the assigned tasks in Stage 1. Observation data of two groups of five students discussed proved that this stage provide many opportunities for students to express creative thinking. Steps of tracking students' creative thinking started with initial questions of the researchers asking the students to present their individual ideas (not discussed with other group members yet) and write them down. Students then discuss the solutions with other members in the groups. This action was done because if students discussed to each other immediately, it was unable to decide whether a student performed any kind of creative thinking or just agreed on the available ideas provided by another students. This situation was carefully recorded and later analyzed by the research team (Figure 6).

- Implementing the selected solutions

Stage 3. Implementing the selected solutions: After completing the assigned group work, students in groups offered one or more solutions. The students then exchanged and analyzed all the solutions together. At the end of Stage 3, students in groups would be able to finalize the solutions they wanted to implement.

Group 1 initially proposed 6 solutions (listed as Solutions from 1-6), group 2 proposed 5 solutions (similar to Solution 2 of Group 1 but use different instruments, from 7-10). However, after discussing together, students all decided to choose the following 10 solutions to implement, including:

1. Read information about the height from the building plan.
2. Use the sun shadow to measure the height based on the principle of congruent triangles.
3. Use the viewfinder (alternative to the sun shadow) to measure the height based on the principle of congruent triangles.
4. Drop a free body from the top of the building to the ground, then measure the falling time to determine the height of the building.
5. Drop the plumb-line from the top of the building to the ground, then determine the length of the wires as this is also the height of the building.
6. Use a lightweight hydrogen filled balloon, tie the balloon with a rope and then release it to fly to the top of the building. The length of the thread is the height of the building.
7. Place the ruler at the ground of the building, standing away from the entire building and take a photo. Put the image into a computer to calculate the building height in proportion to the height measurement on the ruler.
8. Use a specified App on a smartphone to measure the height.
9. Use a barometer based on the fact that atmospheric pressure depends on the height of the air column. By determining the pressure difference at the top and at the ground of the building to determines its height.
10. Use altimeter which is specialized equipment for engineers to measure height.

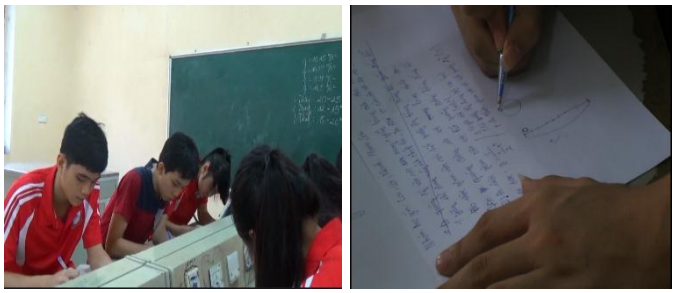

Figure 6. *Students proposed solutions*

Stage 4. Implementing the selected solutions: Students implement the solutions based on the plans they proposed in the group work.

Stage 5. Reporting the findings and recommendation: Students in groups presented processes of their plan implementation and results of their work. Based on experience drawn from the practice, the groups discussed together to find the ultimate solution. This discussion would add more evidence to make the suggested solutions in Stage 2 and 3 become more reliable.

In addition, at the end of Stage 3, the teacher should direct students to plan their implementation as well as instruct them how to collect data, take pictures, and make presentations for reporting purposes. Time allocation for Stage 1 to Stage 3 were 90 minutes which are equivalent to 2 teaching periods in Vietnam and the actions were in the classroom.

Stage 4 was implemented in a week. During this stage, the teacher and research team undertook many sections of observation to collect date, evaluate, and support students when they needed.

Stage 5 was done in 45 minutes which is equivalent to 1 teaching period in Vietnam and the action was also in the classroom.

During the group discussion in Stage 3 and 5, the teacher acted as an organizer or a facilitator that did not undertake much intervention in the groups' work when it was not necessary. Alternatively, the teacher encouraged students to implement their plans to inform the solutions to the assigned problems. At the end of Stage 5, the teacher drew final conclusions, finalized student's ideas and evaluates the performance of each student/ student group (Figure 7).

The implementation of students in groups had identified some unrealistic solutions, as follows:

Solution (1): Students could not find the building plan even when the students had asked the school principal.

Solution (2): Students could not do that because there were sunny days but it did not have bright sunshine and could not use the shadow method.

Solutions (3): Group 2 had done some improvement to increase the accuracy of the measurement. Instead of using bare eyes, which does not provide exact results, the students used the laser pen. Moreover, it is difficult to observe the bright spot of the laser pen with daylight, they therefore moved the experiment time from day-time to night-time. This is a small change but is an innovative idea that expresses creative thinking at high level as this action improves the accuracy of the measurement.

Solutions (4), (5) and (8) could be considered as theoretical solutions as students cannot climb to the top of the building and teachers also do not agree to do this as it may cause serious dangers. Students recommended using aided tools such as sticks.

Solutions (9) and (10) could not be done because students were unable to borrow or rent equipment.

However, after the discussion section, Group 2 proposed and successfully implemented Solution 11, which is a measure of height based on a laser distance measurer.

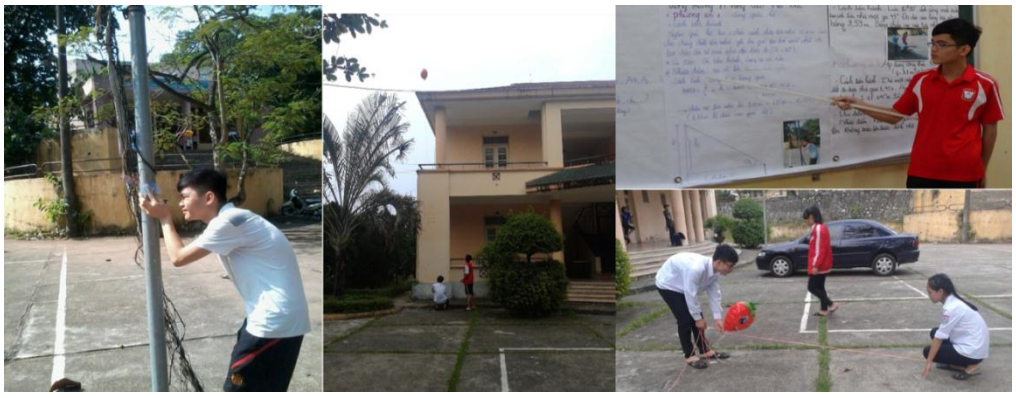

Figure 7. *Students implemented proposed solutions to measure the building's height*

3.4. Analysis of impacts of experimental actions

3.4.1. Evaluation of the designed STEM activities

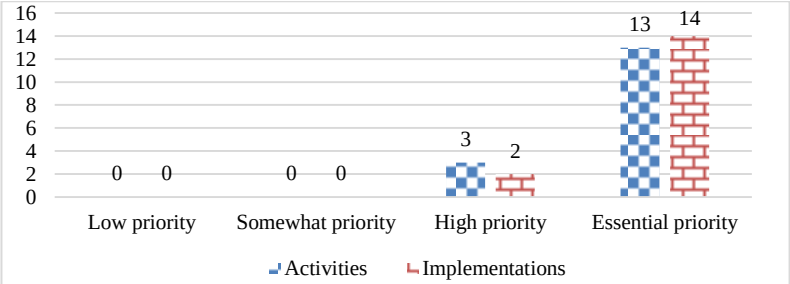

Figure 8. *Results of possibility to develop students' critical thinking by using STEM oriented activities*

In order to evaluate whether the STEM oriented activity "I am an engineer!" had provided students with opportunities to develop creative thinking, the research team collected the evaluation of 16 teachers from the two schools including Viet Bac Highland High School and Luong Ngoc Quyen High School in Thai Nguyen province. The results (see Figure 8) show that most teachers believed the teaching content as well as the process of implementation was very good to develop creative thinking for students.

3.4.2. Overall assessment of providing opportunities to develop students' creative thinking

Based on the manifestations of creative thinking observed in the experimental process, the team summarized specific manifestations of creative thinking emerged from the "I'm an engineer!" activity. The data were collected from three sources that included the teacher's checklist, the self-assessment scores and the peer review assessment. The initial result showed that this activity had created opportunities for the students' creative thinking to be well developed, in particular during the question probing step (Stage 1) and the solution proposing and implementing steps (Stage 2 and 4) when most creative thinking expressions appeared (see Figure 9).

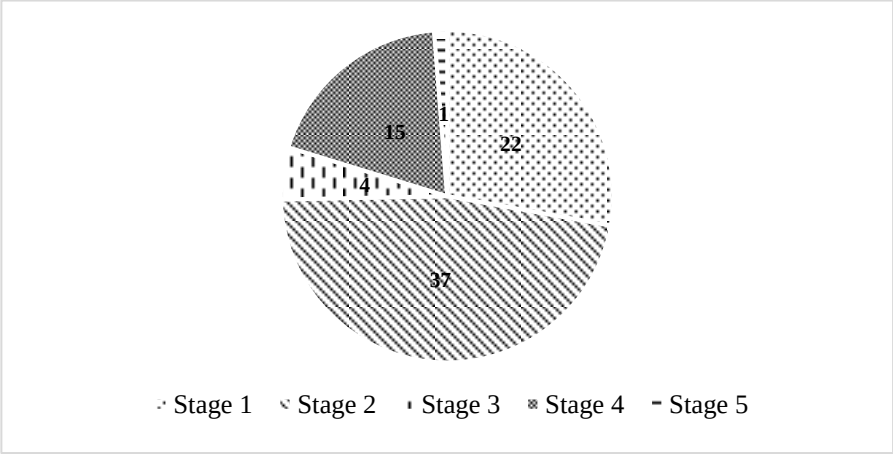

Figure 9. *Number of creative manifestations in different stages of implementing "I am an engineer!" activity (counted per total 10 students)*

This initial result indicates that it is possible to develop students' creative thinking by using STEM oriented activity.

3.4.3. Comparing the expressions of creative thinking between female students and male students

The data also revealed information about whether or not there was a gender difference in the development of creative thinking between female and male students. From the Table 1 – the average results of male and female students in natural science subjects, the differentiation between the two genders is not clear. In some subjects like Chemistry, Biology or Maths, the average results of female students are even better than those of the counterpart, with a gap in each subject's score from 0.2 – 1.0. Meanwhile, the male students got higher scores in just Physics or Technology, with just minimal gap, 0.1. The last subject Informatics showed no difference between two groups. Eventually, the average score of all the natural science subjects' tests of the females student (7.8) is higher than that of the male students (7.6). However, when looking at Table 2, we can see an opposite situation. With the ratio of female students and male students in the experimental group was 6/4, the result showed that the mean score to evaluate the students' creative thinking of female students (6.7) were lower than that of male students (7.8), and the scores of the females in each criterion are all lower than those of the males. This initially drew a conclusion that the test results may not reflect the students' creative activities, and male students might develop better creative thinking than female students in STEM oriented activities.

Table 1. *The average test results of male and female student groups*

	Physics	Chemistry	Biology	Maths	Technology	Informatics	Average scores
Males	7.6	7.0	7.0	7.5	8.0	8.5	**7.6**
Females	7.5	7.5	8.0	7.7	7.9	8.5	**7.8**

Table 2. *Evaluation of students' creative thinking*

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Total score
Males	1.8	1.5	1.5	1.5	1.5	7.8
Females	1.5	1.3	1.2	1.2	1.5	6.7

4. Conclusion and Recommendations

The research findings have drawn the following conclusions and recommendations:

It is possible to develop students' creative thinking through STEM oriented activities;

There are gender influences on the development of students' creative thinking as well as the ability to address problems in STEM activities;

In order to create favorable conditions for students to develop creative thinking, teachers should select and design practical STEM activities related to daily life to make them interested, motivated, and engaged in the process. It is also important to create a safe and friendly learning environment, always encourage students to ask questions, being creative, and propose new and unexpected ideas.

Research results should be expanded to a broader, longer-term research to increase its validity and reliability.

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