Developing critical thinking of students through STEM educational orientation program in Vietnam

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Abstract. One of the requirements in teaching process is to develop the thinking of learners. Thus, how an educator could organize teaching activities in order to enable the critical thinking ability of students in high school? Based on the stages of the solving process in the learning process of the student, the expression of critical thinking in each stage, the author would like to suggest educational orientation program following STEM system (STEM activities) in order to develop critical thinking of students. This article analyses the impact of using STEM activities on the development of students in some high schools in mountainous regions in the northern part of Vietnam. The results show the development of critical thinking of students through STEM activities and some superior suggestions for using STEM activities to motivate critical thinking of students in high school.

Keywords: STEM education, Critical thinking, Physics teaching

1. Introduction

Critical thinking is one of the important skills that each individual in the 21st century should know in order to work and live effectively in the global society. Critical thinking is a high-level skill, not only analyses, identifies and evaluates information or arguments from different sources but also thinks of private thought. It is complicated to accomplish; however, it is not impossible in teaching and one of the most effective ways is to take students into problem-solving activities [1]. In the world, many authors have been studied about critical thinking of students. However, there are not any specific studies concerned critical thinking of students in high school through STEM educational orientation program [7].

The new curriculum in Vietnam (July, 2017) indicates that the importance and enhancement of STEM activities is a radical innovation of the new curriculum. In particular, STEM educational orientation program is known as an effective solution in the development of critical thinking, which every high school with a new curriculum is aiming for. Based on STEM activities, students not only perceive scientific knowledge but also improve necessary abilities, creative thinking, critical thinking, and solving abilities [6]. STEM activities help the school incorporate academic knowledge in books with life and society; help students balance physical and mental, develop thinking, especially critical thinking.
On the other hand, the demand for jobs related to the STEM field is increasing and skills of labour in the 21st century are required, and STEM program can support for necessary skills. Therefore, applying for STEM educational orientation program in teaching in high schools can bring effective results and meet the requirements of society.

The issue is how to create STEM educational orientation program so that students can develop critical thinking. Aspects of critical thinking of students during STEM educational orientation program were analyzed. Definitions as to what Critical thinking is vary but are often rather involved, complex and difficult to understand. Perhaps a more useable definition for current affairs classes might be Fisher and Scriven’s “Critical thinking is skilled, and active interpretation and evaluation of observations and communications, information and argumentation” [2].

According to Lipman (2003), “Critical thinking is involved in all responsible interpretation (the production of meaning), and all responsible translation (the preservation of meaning)”. These views have been summarized in "Developing Thinking Developing Learning" [5]. According to the study of the aspects of critical thinking by Luyen (2009) and Lipman (2003), and the study of problem-solving characteristics, we have identified the basic expressions of critical thinking of students during STEM activities as below:

1. Identifying new matters;
2. Giving a reliable prediction;
3. Suggesting alternative options;
4. Successfully executing chosen options;
5. Improving the chosen options;
6. Selecting the optimal option;
7. Applying knowledge to tackle problems in every situation.

Before each problem encountered, the learner will consider how to find the reasonable and unreasonable points, which means critical thinking. STEM activities are built in order to create more opportunities for students when solving problems.

2. Methodology
The research methodology of this study is qualitative research. Based on targets of development thinking of students (critical thinking), researchers figured out some initial observations: STEM activities can improve critical thinking skill of learners. According to this result, researchers built a survey to find out the difficulties as well as actual demands of students about STEM educational orientation program, built a system consisting of 6 STEM activities and accomplished this system to improve critical thinking for students. The effect of this impact will be measured based on critical thinking scale during the time students tackle problems in the assigned tasks. Analysing results will help answer the questions below:
- What is the effect of STEM education on the development of critical thinking?
- How does critical thinking relate to learning outcomes or to creative thinking?
- In term of demographic factors, how do they influence the development of critical thinking ability of students?

2.1 Target group
Target group were randomly selected, including 52 students grade 10, divided into 10 groups of 4 schools in some mountainous provinces at the northern part of Vietnam. At the present, the pressure and expectation from examinations and grade points in Vietnam are remarkably high. Parents want their children to gain high academic achievements (grades), and they are not concerned about other factors such as the ability to solve problems or to develop critical thinking ability of their children. That is the reason why the authors could not invite all students in one class taking part in activities which we have created. Besides, with a big number of students taking part in at the same time would
be a big difficulty for the research in observing and evaluating critical thinking level of each individual. Instead of this, the person in charge of this paper had volunteers under the permission of the school and parents. Each member of this research has worked with a group of students for 2 to 3 months, 1 to 2 days per week including STEM activities. Every group, the researchers spent about 8 days working with them, sometimes the process lasted about 2 months as students had to join other activities of the school.

The pedagogical experiment process was carried out with students at Grade 10 chosen randomly, in some high schools in the northern part of Vietnam as showed in Table 1.

Table 1. Research subjects and time

| Group | Research time   | Research subjects                                                                 | Number of students | Areas            |
|-------|-----------------|----------------------------------------------------------------------------------|--------------------|-----------------|
| 1-2   | From 12/10/2016 to 07/12/2016 | Students in class 10A1 of Vung Cao Viet Bac High school – Thai Nguyen province | 10 Students        | Moutainous area |
| 3-4   | From 12/10/2016 to 14/12/2016 | Students in class 10A2 of Vung Cao Viet Bac high school – Thai Nguyen province | 10 Students        | Moutainous area |
| 5-6   | From 15/10/2016 to 22/12/2016 | Students in Physics class 10 of Thai Nguyen gifted high school – Thai Nguyen province | 10 Students        | Urban area      |
| 7-8   | From 16/10/2017 to 28/12/2017 | Students in class 10A9 of Luong Ngoc Quyen high school – Thai Nguyen province | 12 Students        | Urban area      |
| 9-10  | From 10/10/2017 to 18/01/2018 | Students in Physics class 10 of Ha Long gifted high school – Quang Ninh province | 10 Students        | Urban area      |
2.2 Intervention of STEM activities executing process for develop students’ critical thinking

In order to nourish and develop students’ critical thinking and creative thinking, it is required that the teaching process needs to boost students’ creativeness, such as: encouraging them to ask questions, exchanging ideas, discussing logically, problem-solving. Students are allowed and provided the best conditions to carry out the option that they suggested or to defend their ideas and results. Hence, we propose a step-by-step process which is illustrated in Figure 1 [8]; [9].

**Figure 1.** Steps for organizing STEM activities

Step 1 Practical matters: From real-life problems, the teacher and students should come up with a specific problem with the need to tackle it. For example: questioning them to measure their houses’ height. Or how to create a basic boat? Is it possible to design anti-flood/earthquake-resistant houses?...

Step 2 Suggesting alternatives: From the assigned task, students will have discussions in groups to suggest options to tackle the task they got from Step 1.

Step 3 Discussing on alternatives: After working in teams, students could bring out two or more options. Then they will present their ideas in front of the class to analyze and collect feedback from other teams. At the end of this step, teams will decide their one or more options.

Step 4 Executing alternatives: After making a decision from the third step, student teams will start to carry out their selected options. Here students could do only one or more alternatives. However, students are required to collect important data to prove their results and discussions.

Step 5 Reporting on results of executing alternatives: From the above steps, all groups will present the results of their tasks. With the evidence and data gained, the groups will discuss with each other to find the optimal solution. This discussion will add to the conviction of the conclusions after the first discussions in Step 3. Although previous opinions might be correct, might be not, there is a lack of the persuasiveness since they have not tested and proved (most of the opinions are suggested based on personal experience, theories). Nevertheless, in this step students will prove their findings/researches.
At the end of Step 3, the teacher should ask students to plan their tasks, to collect needed information for reports (data collecting, photo illustrating, report presenting, ...). Also, teachers should provide and instruct students to make their own plans and settle the working timetables with them. During outdoor research activities, teachers should always supervise students’ safety. Moreover, this could help teachers to evaluate each individual better.

During discussing time (Step 3, Step 5) teachers play the role as the host, encourage students to generate and defense for their own ideas, and avoid unnecessary intervention. At the end of Step 5, teachers become the person who gives final decisions and evaluation to both students and their performances.

2.3 Data Collection and Analysis

Students critical thinking ability was evaluated while they were doing assigned tasks in the intervention of STEM activities executing process for develop students’ critical thinking. The tool of the critical thinking evaluation (CTE) form was developed regarding on 7 aspects of basic expressions of critical thinking [3]; [4]. These aspects included (1) Identifying new matters; (2) Giving a reliable prediction; (3) Suggesting alternative options; (4) Successfully executing chosen options; (5) Improving the chosen options; (6) Selecting the optimal option; and (7) Applying knowledge to tackle problems in every situation.

To collect data of students’ critical thinking when they on tasks, the CTE form was completed as the table 2 and 3. Data points obtained from the three main points: observation points (a); self-assessment (b); peer-to-peer review (c) and teamwork evaluation (d). After that, the final scores of each student for each STEM activity will be calculated as the average of all the points.

Table 2. Critical thinking evaluation form based on the observation chart

| Evaluated student’s full name: ……………………………………….. |
|---------------------------------------------------------------|
| **Criteria** | **Levels** | **Level 1** | **Level 2** | **Level 3** | **Evaluation points** |
|----------------|-------------|-------------|-------------|-------------|----------------------|
| 1) Bring out questions about a process, a thing or a phenomenon; a technical application, … that they encounter in daily life | Level 1 | Level 2 | Level 3 | Evaluation points |
| 2) Suggest solutions to solve the newfound problem | Level 1 | Level 2 | Level 3 | Evaluation points |
| 3) Have proper basis points during discussing process about a specific problem | Level 1 | Level 2 | Level 3 | Evaluation points |
| 4) Can evaluate other viewpoints and prepare for arguments | Level 1 | Level 2 | Level 3 | Evaluation points |
| 5) Adjust their own opinions and activities when a new information is found | Level 1 | Level 2 | Level 3 | Evaluation points |
| 6) Select the optimal options in problem-solving process | Level 1 | Level 2 | Level 3 | Evaluation points |
Table 2 is an example of an observation form of a teacher for each student. In which, the form will clearly state what students can achieve after learning or doing an activity. Each student will receive their own assessment via the form. This is also the reason why the researchers did not choose a large group of students since that would make the observation and follow-up difficult. To achieve the wanted results, the research group has chosen to record a full video when students were working and discussing. Then the videos will be reviewed, students' performances will be evaluated and given points based on criteria in the above table. Level 1 means 1 point, while level 3 means 3 points. As mentioned earlier, this practice will only work with small group of students (in this study, the authors only allow 5 to 6 people per group) since other factors such as: discussing noise or recording difficulties, should not affect students during their activities to bring the most realistic reflection of thinking or working process of all students.

**Table 3. Self-assessment and peer-to-peer review form**

Reviewer’s full name: ........................................................................................................

| Number | Full name   | Review criteria                                                                 |
|--------|-------------|---------------------------------------------------------------------------------|
| 1      | Nguyen Van A| 1) Bring out questions about a process, a thing or a phenomenon; a technical application, … that they encounter in daily life |
| 2      | Nguyen Van B| 2) Have proper basis points during discussing process about a specific problem    |
| 3      | …………      | 3) Have valuable contribution to other members' opinions                        |
|        |             | 4) Listen and receive feedback from other members                                |
|        |             | 5) Select the optimal options in problem-solving process                          |

Table 3 is the self-assessment and peer-to-peer review form and it will be distributed to each student. When the reviewer (student A) evaluates himself, the points in the column with his name (Nguyen Van A) will be his own assessment, other points are from peer-to-peer reviews. Student A also will not be allowed to evaluate the whole class but his team members to ensure the reliability since he only works with 4 other members of the group (in a group of 5). Of course, before distributing the forms, teachers are expected to explain clearly every criterion in it and instruct them the evaluating steps to get the highest reliability. This form will be given to the class at the end of the activity (Step 5).

Besides, the researchers also collect other data through in-depth interviews during and after each STEM activity (if necessary) to contribute to the evaluation process in the above forms.
3. Research Findings

One of the most important targets in the teaching process is to create and develop thinking of learners, especially critical thinking. Enormous ways could be utilized to achieve this target, and STEM educational orientation program is one way. The paper will clarify the general view of organizing STEM activities and motivating critical thinking of students in high school and then examine students’ critical thinking ability in the intervention of STEM activities.

3.1 General view of STEM activities in high schools

Researchers have carried out the survey from July, 2015 to August, 2015 on 42 teachers teaching Sciences and 442 students from different high schools such as Thai Nguyen High School, Pho Yen High School, Chu Van An High School, Phu Luong High School, Dai Tu High School of Thai Nguyen Province and some neighboring provinces. The result of the survey presented as follows:

- Sciences’ teachers: They used to try organizing STEM activities in teaching, however, the rate is still low (Figure 2), the frequency rate is extremely small (5%). The reason is that teachers have to follow the teaching plan of the school, meanwhile, STEM activities would take a lot of time. Another reason comes from the evaluation process, examinations in Vietnam are not concerned about ability evaluation. To deeply understand about this situation, researchers have had a meeting with teachers and known that many teachers were not trained or introduced the way to organize STEM activities and the way to evaluate students through those activities as well.

- Students: The result finds out that during studying time, students were absolutely excited about observing one physics experiment and they would like to do a specific experiment by themselves. They also had many questions need to be answered. Most students enjoyed lessons with STEM activities. This is one of the factors that urge the need to conduct this study.

3.2 Students’ critical thinking ability in the intervention of STEM activities

Students’ critical thinking ability was examined when they on tasks in the STEM education activities. The findings about students’ critical thinking ability will be calified as following: a) General evaluation about the development of students’ critical thinking ability, b) Comparing the development of critical thinking ability between male and female students, c) the development of critical thinking ability for students with different background, and d) relationship between learning outcomes and critical thinking development.
a. General evaluation about the development of students’ critical thinking ability

During the process of designing STEM activities, the researchers decided that the difficulty level, as well as the opportunities, should be the same in the first activity (Activity 1) and the last one (Activity 6) to let students express themselves equally. The analysis result shows that, by participating in STEM activities, most students increased their points of critical thinking ability (based on the comparison between Activity 1 and Activity 6), however, the change is not similar among students in researched groups. Some students noticeably rose their points (about 1 – 2 points), but some almost remained unchanged (Figure 3). Results also specified that no students experienced unusual increase/decrease (2 or more points). In conclusion, STEM activities can change students’ critical thinking ability.

![Figure 3 The change in critical thinking points of students](image)

b. Comparing the development of critical thinking ability between male and female students

The researchers were also curious about if there is a difference between genders in term of developing critical thinking ability or not. Here is the final outcome: The critical thinking average points of female students are lower than that of male students; the increase in critical thinking points of male also higher than that of female students (Table 4). This indicates that male students have better critical thinking ability, though the difference is not remarkable. This also allows the researchers to come to the conclusion: the psychological barriers in communication and the lack of self-confidence have hindered female from the development of critical thinking ability. Besides, it could be that STEM field was not the strengths of them. So it is recommended that each student group should have the same numbers of male and female numbers in order to balance out the differences. That could let students with higher critical thinking points help ones with lower, and they can learn from each other since male students tend to do heavy work while female is much better in doing activities required sophistication, skilfulness. By combining these two suggestions, each student could do their best in STEM activities.

| Table 4. Critical thinking points of male and female students |
|---------------------------------------------------------------|
| **Average** | **Average increase** |
| Male         | 7.2 | 1.1 |
| Female       | 6.4 | 0.5 |
c. The development of critical thinking ability for students with different background

From Figure 4, everyone could see that students in mountainous, remote and isolated areas have low critical thinking scores, low academic achievement, whereas students in the cultural and administrative centers of the city did get higher critical thinking ability and academic results. The main reason could be that students coming from mountainous areas are limited to have experiments, extracurricular activities, science clubs, learning activities related to practical tasks. In addition, these groups are required by the school to stay in their dormitories and could only go outside with permissions. While city-based students are more likely to live and work independently, receive better practical knowledge, their opportunities of developing critical thinking ability may be higher. Thus, it can be said that the living environment of a student can influence his ability to develop critical thinking.

![Figure 4: Critical thinking point, point average academic results](image-url)
d. Relationship between learning outcomes and critical thinking development

To evaluate the correlation between academic performance and critical thinking ability, the research team has taken the most recent grade point average for students in Maths, Physics, Chemistry, Biology, Computer Science and Technology to compare (Figure 4). The results show that students with high academic scores also develop critical thinking better. This made the researchers quite unexpected compared to the team's prediction before doing pedagogical experiments. This fact suggests that classroom assessments have already included comments about critical thinking assessments, or, in other words, good assessments. This could be considered as a model for evaluating student learning outcomes in the future.

4. Conclusions

The research results obtained from pedagogical experiments showed that:

- Critical thinking ability of students can be developed through STEM activities
- Students with high level of critical thinking also have high academic achievement and vice versa
- Teachers' assessments at the experimental schools have paid close attention to the student's critical thinking
- Gender can influence the development of critical thinking and the ability to solve problems in STEM activities
- Organizing STEM activities is suitable for all students from highland and mountainous areas to the urban, metropolitan places; from average to good academic performance, from normal school to gifted high school students, both male and female
- To facilitate the development of critical thinking, teachers should select and design practical STEM activities that are close to their daily lives in order to stimulate interest and motivation for their students. Also, teachers have to create a safe and friendly learning environment, always encourage students to ask questions, criticize and contribute ideas, ...
- Research results should be tested on a broader range of subjects, longer timeline so that conclusions could be more persuasive

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