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DEVELOPING STUDENTS' CRITICAL THINKING COMPETENCE IN TEACHING THE CHAPTER "*DERIVATIVES OF HYDROCARBON AND POLYMERS*" - CHEMISTRY 9

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Abstract. The development of critical thinking competence for students (CTCFS) is one of the essential tasks of teachers in the 4.0 period because it is one of the essential competence required. The article mentions the structure of component competence, and based on that, designs the rubric of the CTCFS assessment table. The assessment table is generally built to evaluate the critical thinking ability of grade 9 students in teaching and learning Chemistry. To be able to implement each lesson in practice, teachers need to follow the criteria to feature more details in the specific lesson and teaching methods.

Keywords: critical thinking, project-based learning, competence, chemistry, rubric.

1. Introduction

Recently, the phrase "Essential skills in 21st century" has become popular in the education field. According to the definition of the Organization for Assessment and Teaching of 21st Century Skills (AT21CS) [1], at the University of Melbourne (Australia) [2], 21st century skills includes 4 main groups of soft skills which are thinking skills, work skills, skills in using work tools and skills in living a global society. The thinking skills include creativity, critical thinking, problem-solving skills, decision-making skills, and lifelong learning. In particular, critical thinking is a core skill and is focused on the educational process across countries nowadays. The leading countries in education such as Australia, the United States, etc. mainly focus on critical thinking. Criteria frameworks are set up to assess learners' critical thinking ability at different grades and levels.

According to Nur Wahidah Abd Hakim and Corrienna Abdul Talib [3], there are many reports on the incorporation of critical thinking into teaching and learning. For example, researchers focused on instructional strategies for fostering students" critical thinking such as inquiry-based learning [4], collaborative learning [5], and activity-based cooperative learning [6].

In Vietnam, developing students' critical thinking capacity in teaching Chemistry is necessary and it should be focused in order to create generations of students in the 4.0 period with confidence, bravery, and the ability to solve the problem scientifically. This ability also helps students to be able to flexibly handle real situations encountered in practice. Some papers have already mentioned the necessity of developing critical thinking competence for students in

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Viet Nam such as "Creative thinking in STEM education according to the general education program", authors Tuong Duy Hai and Nguyen Vo Thanh Viet have given the manifestations of critical thinking in students and the expression of critical thinking on the requirements of the general education program, propose some possibilities for fostering students' critical thinking through STEM education [7].

"Training critical thinking skills for students in teaching the chapter "Converting matter and energy" (Biology 11)", authors Nguyen Bich Ngoc, Phan Thi Thanh Hoi have applied the process of training critical thinking skills in teaching lessons 19 and 20 (Biology 11) which shows the feasibility of the process. Applying the process can train students' thinking skills [8].

"Designing questions to foster students' critical thinking in teaching botany - Biology 11", authors Dang Thi Da Thuy, Nguyen Thi Dieu Phuong, and Pham Thi Phuong Anh have determined components of critical thinking, propose a process to design questions to train critical thinking and apply this process to build types of questions to practice critical thinking skills in teaching topic “Plant growth and development” [9].

In general, the research on developing critical thinking in the teaching process in high schools is a matter of interest. However, at present, there are few researches on the development of this competence in chemistry teaching, especially in chemistry teaching at the lower secondary level in Vietnam.

The article presents the structure of students' critical thinking competence, as well as presents the tools used to evaluate the capacity of critical thinking (rubrics) with the focal point in grade 9 Chemistry. The article also applies the rubrics to evaluate students' critical thinking competence in teaching project - Simple rocket model in acetic acid lesson.

2. Content

In the process of implementing the project, we have applied a combination of research methods such as research methodology, implementation research method, information processing method, systematic statistics with research. The object of the study is developing the critical thinking competence and the use of project-based learning methods. We conducted the pedagogical experiment in grade 9 at Cau Giay Secondary School, Cau Giay district, Hanoi in 2021.

2.1. Critical thinking competence

As the Center for teaching and learning at Washington University referred, critical thinking competence includes specific competence such as identifying and generalizing problems; recognizing the content and related issues; collecting and analyzing information; exchanging and counter-argue other opinions; evaluating and drawing conclusions [10].

According to Paul et al. [11] critical thinking framework, critical thinking competence has four elements: Identify purposes and question at issue; analyze supporting data and evidence; generate assumptions and different point of view at a problem; evaluate implications, conclusions, and consequences. Referencing based on documents of the above authors, we constructed the structure of critical thinking described in Figure 1.

Referring to the papers above, we identify 5 components of critical thinking competence as follows: identify issues, generate ideas, analyze and connect ideas, create hypotheses and find answers, assess conclusions and implications. Each competence includes criteria of the individual when a student working independently and working in a group during the critical thinking process.

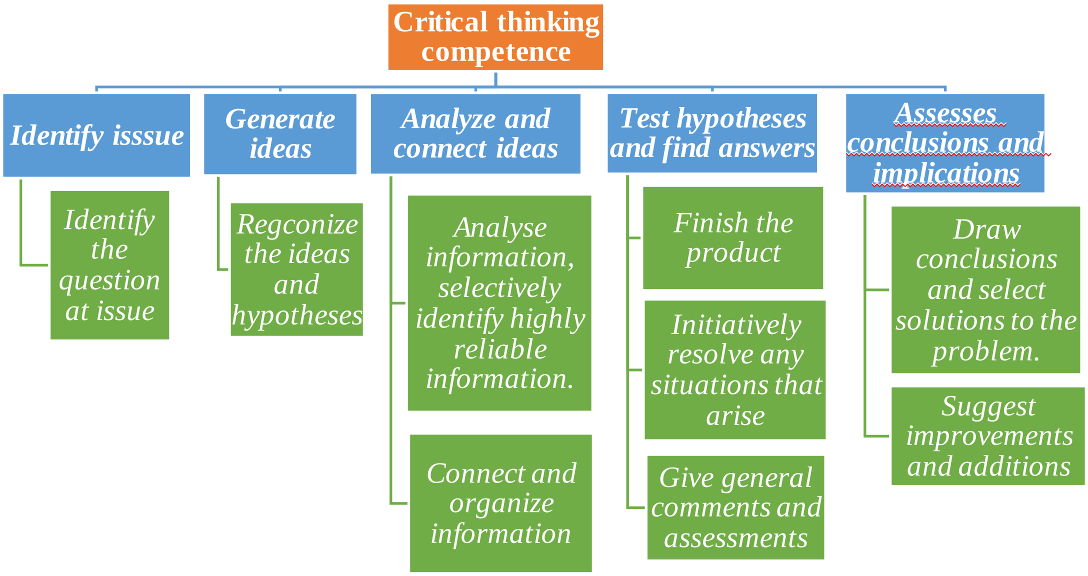

Figure 1. Structure of critical thinking competence

2.2. Critical thinking rubric

Based on the reference of the Censer for Teaching and Learning at Washington University on criteria of critical thinking assessment [10-12] and Australian curriculum [2] we adjusted and deduced the rubric of critical thinking as described in Table 1.

Table 1. The rubric of critical thinking

No.	Criteria	Indices	Rating scale		
			Level 3	***Level 2***	***Level 1***
1	Identify issues	1.1. Identify the question at issues (CT1)	Clearly identify issues in learning and doing a project.	Somewhat identify general issues and be quite passive.	Fail to identify the issues in learning.
2	Generate ideas	2.1. Recognize the ideas and hypotheses (CT2.1)	State, explain and give examples of all the empirical and theoretical contexts relevant to all the main stakeholders and always propose hypotheses.	State the general influences of empirical and theoretical contexts on stakeholders and need support in explaining and giving examples and propose hypotheses.	Cannot state, explain or give examples of empirical and theoretical contexts on stakeholders within appropriate support. Do not consider or propose hypotheses.

3	Analysed and connect the ideas	3.1. Analyze information, selectively identify highly reliable information. (CT3.1)	Analyse information, summarise main ideas, clearly and precisely restate. Show the competence in searching reliable sources and accurate information.	Summarize main ideas and restate quite with some mistakes. Show the competence in searching for reliable information.	Cannot summarize main ideas and restate or restate incorrectly. Do not use reliable information.
		3.2. Connect and organize information. (CT3.2)	Connect and organize information, logicalresources, and materials pertinent to the addressed issues. Clearly and precisely formulate a point of view to test the ideas.	Connect and organize information, reasonably resources, and materials pertinent to the addressed issues. Show little point of view and lack of logic.	Cannot connect information. All information is simple and incoherent.
4	Test hypotheses and find answers	4.1. Finish the product (CT4.1)	Complete the product proposed and update the former ideas.	Complete the product.	Do not complete the product.
		4.2. Initiatively resolve any situations that arise (CT4.2)	Be proactive in proving the hypothesis.	Be passive in proving the hypothesis.	Do not care about any situations.
		4.3. Give general comments and assessments (CT4.3)	Always give well-founded comments and evaluations.	Give comments and evaluations with a few inappropriate ones.	Cannot give comments and evaluations.
5	Assesses conclusions and implica-tions	5.1. Draw conclusions and select solutions to the problem. (CT5.1)	Conclude and generalize issues to choose the reasonable, utilized, and creative solution.	Conclude and generalize issues with some mistakes and choose an inappropriate solution.	Cannot conclude or generalize issues or choose a solution.

		5.2. Suggest improvements and additions (CT5.2)	Provide fully additional development and improvement to the product based on the counter-argue comments.	Provide some additional development and improvement to the product based on the counter-argue comments.	Cannot provide any additional development and improvement to the product.

2.3. The procedure to develop critical thinking through teaching grade 9 Chemistry

Based on the described traits of critical thinking in 2.2, a 5-step procedure is suggested as follow:

**** Step 1. Identify issues***

The teacher presents a situation or a problem that requires critical thinking. It should be practical, comprehensive, and suited to the biopsychological development of students. The students are encouraged to think critically to solve the problem.

In teaching Chemistry, the teacher can introduce real-life problems related to the properties of substances in order to foster students' critical thinking skills

The students listen and engage actively.

**** Step 2. Generate ideas***

- *Multidimensional consideration*: group discussions are needed to address questions. These questions should have various solutions.

- *Idea rearrangement*: Students discuss in groups to connect and reconfigure their ideas to solve the set task.

**** Step 3. Analyze and connect the ideas***

- *Material gathering*: Obtaining materials and information from a diverse range of sources and assessing their credibility mean students can utilize the Internet, journals, or materials provided by their teachers.

- *Information analysis*: Students analyze and assess the information garnered, in relation to the set situation to find convincing solutions.

- *Information connection and logical sequencing*: From the information obtained and collective cognitive work, students suggest possible solutions, which can be in the form of a design, a plan, etc.

**** Step 4. Test hypotheses and find answers***

- *Reasoning:* Students hypothesize a solution using suitable explanations and examples.

- *Experimenting:* Students conduct tests to check the hypothesis by doing practical work, drawing conclusions, and finding areas that need improvement.

- *Reflection and feedback:* Students listen to ideas and provide positive, constructive feedback about other students' reasoning. They can also present their ideas, counter arguing other viewpoints.

+ *Adjustment:* Students consider and rectify the flaws in their reasoning.

**** Step 5. Assesses conclusions and implications***

After discussing as a class, based on reviews from all groups, the groups can evaluate themselves and others. The teacher summarizes bullet points, providing a general view of the key ideas of the lesson/topic.

2.4. Example illustrating the process of developing students' critical thinking ability in teaching project - Simple rocket model applied to acetic acid lesson, grade 9 Organic Chemistry

**** Step 1. Identify issues (develop CT1)***

Questions at issue: How can rockets go up? Which chemical reaction with acid involved has characteristics suitable for the task of propelling rockets up?

Problem: The teacher let the students observe the video of the rocket's launch. The teacher questioned how rockets can fly, posing the problem of designing a simple rocket model using acetic acid as fuel.

Students work individually to answer questions related to the teacher's lead video and come up with ideas for how to use the acetic acid reaction.

**** Step 2. Generate ideas (develop CT2, CT3.1)***

- *Multi-dimensional thinking on the issue*: Group discussion presents tasks and questions related to rocket operation and structure. Learn about the properties of acetic acid and answer using the KWL technique. The teacher introduces students to the common name of acetic acid, vinegar, and then asks students to recall and write in column “K” the characteristics of vinegar that they already know and make predictions about the chemical properties of acetic acid based on knowledge of inorganic acids. Then, the teacher organizes a group discussion for students to fill in column “W” what students need/want to know in order to solve the problem posed; Students search and collect information through observing real samples, conducting experiments, and searching textbooks/internets to record in column” L”.

- *Transform ideas:* Students work in groups to connect and make connections between the properties of acetic acid and rocket fuel. Make a simple rocket model design drawing.

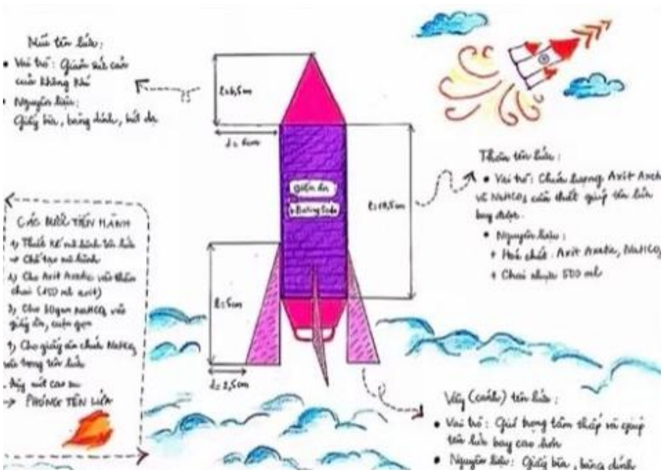

Figure 2. Students’ rocket design

**** Step 3. Analyze and connect the ideas (develop CT3.2)***

- *Material gathering*: Collect relevant documents and information, using a variety of sources such as textbooks, the internet, etc. about the properties of acetic acid.

- *Information analysis*: Conduct experiments to learn about gaseous reactions of acetic acid that can be used as fuel for flying rockets such as: reacting with metals, carbonates, etc.

- *Information connection and logical sequencing:* From the information gathered, the students suggested that the reaction used in the rocket would be the reaction between acetic acid and baking soda.

**** Step 4. Test hypotheses and find answers (develop CT4.1; CT4.2)***

- *Reasoning:* Students make hypotheses about the flight principle and rocket's structure, fuel quantity, etc. The teacher can give suggestions for questions. The following examples show that students were able to hypothesize.

Teacher: "How much substance is needed for the rocket to fly?"

Students: "About a third of the volume of a rocket bottle, smaller volume is not enough to pressurize the rocket to fly, the bigger volume reduces the amount of gas that can be contained".

Teacher: "Proposing experiments to investigate substances' quantity".

Students: "Use a zip bag or inflate balloons with baking powder and vinegar".

Teacher: "How to know how far the rocket flew for comparison between tests?".

Students: "Compare the height of the tests with the height of the house wall".

In addition, students can ask themselves questions such as: How to make rockets fly straight? What factors affect how high a rocket can fly? How to optimize that factor?

Figure 3. Experiment on the number of substances

- *Experimenting:* Students make rockets and test models in reality, solve arising problems, and test their hypotheses.

- *Reflection and feedback:* Students give ideas and work together to solve problems that arise during the experiment.

- *Adjustment*: Consider, correct mistakes in the original design and fine-tune the product better.

Question 1: "How can the generated gas be ejected to create thrust for the rocket without the two reactants falling apart before the reaction occurs? How to reduce response time?

Adjustment: "Roll the baking powder into a thin layer of paper"

Question 2: "When the rocket goes up, it will be subject to air resistance, how can we reduce that resistance?"

Adjustment: "Use rocket wings made of hard materials for strong wings. Fold the rocket wings firmly and accurately so that the rocket does not swirl, reducing friction. Wings are made of flat materials, avoiding convexity".

Figure 4. Students' rocket model

Figure 5. Rocket model testing

**** Step 5. Assesses conclusions and implications (develop CT4.3, CT5.2, CT5.3)***

The groups conduct product display, and critique according to the organization of the teacher. Each group is required to come up with a minimum of 5 questions/assessments and issues to discuss. The ideas will be listened to and critiqued by students. Finally, the teacher will ask some additional questions and conclude the knowledge for the students.

2.5. Pedagogical experiment

We perform a pedagogical experiment by using a project-based learning method in project "Simple rocket design" on 9A1 class, Cau Giay Junior High School (class of 2020 - 2021) when teaching "*Acetic acid*" (Chemistry 9) lesson. The results of implementing mentioned theory and rubrics for critical thinking assessment are demonstrated in the critical thinking's tests outcome as below:

**** Quantitative assessment results***

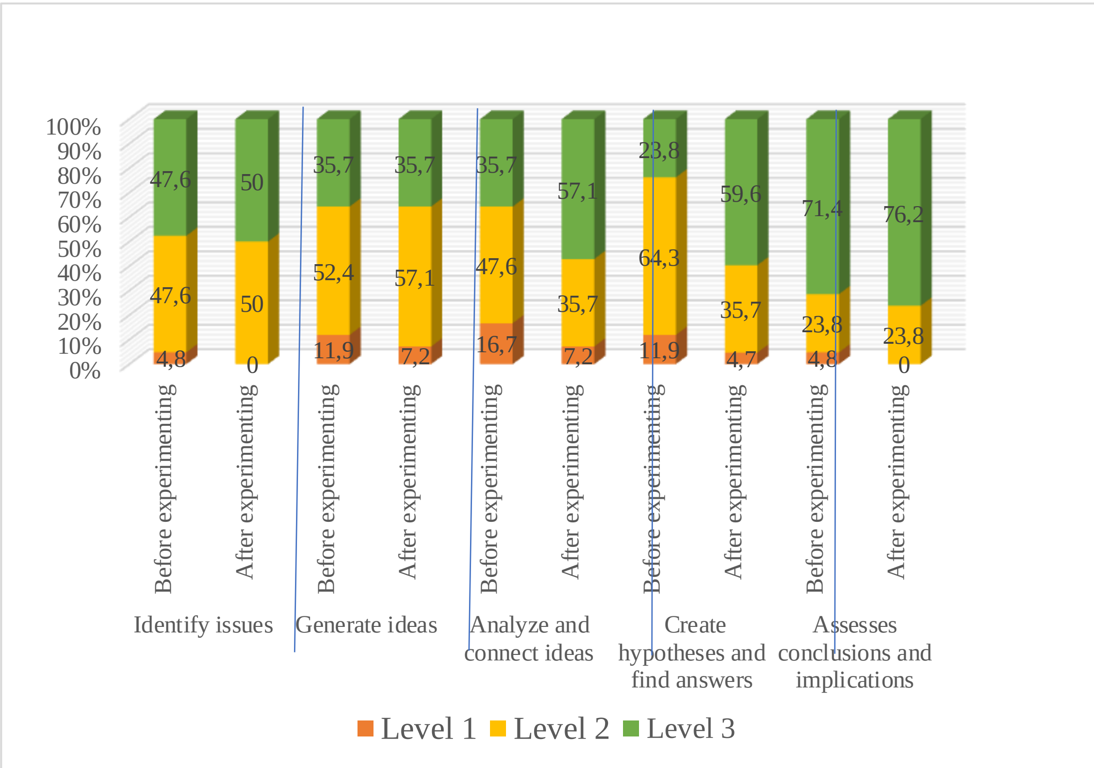

Figure 6. Evaluation of the development of student's critical thinking

Figure 6 shows the progress of students in critical thinking skills. Specifically, identify issues skills, before the experiment, 4.8% of students did not recognize the problem, 47.6% of the students recognized the problem correctly. After the experiment, all students know the problem. After the experiment, students had this skill at a high level, 100% of them were aware of the problem, the percentage of students correctly recognized (level 3) increased to 50%. Thus, students have already had this skill, but most students only use it at a basic level. With the skill of generating ideas, the percentage of students at level 1 after the experiment has decreased by 7.7% compared to before the experiment (before the experiment is 11.9% and after the experiment is 7.2%). This initially shows that there are students who have begun to associate and explore relationships related to the problem, thereby coming up with ideas to solve the problem.

Quantitative results in the skills of analyzing and connecting ideas vary widely at all three levels. At level 1, the % difference in students' rate is 9.5%. In particular, after the experiment, nearly 60% of students reached level 3, while this number at the time before the experiment was only 35.7%. Thus, the experimentation process has had obvious effects on the ability to analyze and connect ideas in students. After the experiment, most students know how to search and analyze information selectively, and know how to see multi-dimensional problems.

The biggest pre- and post-experiment change in critical thinking skills is the component of creating hypotheses and finding answers. Before the experiment, the rate of students at level 3 was 23.8%. After that, this number was up to 59.6%, 2.5 times higher than before. In contrast, at level 2, the rate of students before the experiment was 64.3%, up to 28.6% higher than after the experiment. After the experiment, students were confident, actively making hypotheses and experimenting with them.

With assessment and conclusion skills, the difference before and after the experiment is not much. This disparity still follows the same general trend as other critical thinking skills. After the experiment, the percentage of students at level 1 decreased compared to before the experiment and vice versa at level 3.

In addition to the quantitative results according to the criteria-based assessment sheets, the results of the quantitative analysis of the two tests also indirectly prove that the development of critical thinking helps students achieve higher results in learning.

Table 2. Table of the frequency distribution of first test scores of the control and experimental classes

Class		**Xi score**										**Mean $\overline{X}$**
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	
Control	Quantity	0	1	1	2	8	12	9	7	2		**6.2**
	%	0	2.4	2.4	4.8	19.0	28.6	21.4	16.7	4.7	0	
Experimental	Quantity	0	0	0	0	4	7	11	7	10	3	**7.5**
	%	0	0	0	0	9.5	16.7	26.2	16.7	23.8	7.1	

Table 3. Parameters featured in first test results

Class	**Number of students**	$\overline{X}$	**SD**	ε	$\overline{X} = \mathrm{X} \pm \varepsilon$
Control	42	6.2	1.51	0.08	6.2 ± 0.08
Experimental	42	7.5	1.45	0.06	7.5 ± 0.06

Table 4. Table of the frequency distribution of second test scores of the control and experimental classes

Class		**Xi score**										**Mean $\overline{X}$**
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	
Control	Quantity	0	1	1	2	9	10	12	6	1	0	**6.17**
	%	0.0	2.4	2.4	4.7	21.4	23.8	28.6	14.3	2.4	0.0	
Exp.	Quantity	0	0	0	1	5	7	14	9	4	2	**7.07**
	%	0.0	0.0	0.0	2.4	11.9	16.7	33.3	21.4	9.5	4.8	

Table 5. Parameters featured in first test results

Class	**Number of students**	$\bar{X}$	**SD**	ε	$\bar{X} = X \pm \varepsilon$
Control	42	6.17	1.44	0.09	6.17 ± 0.09
Experimental	42	7.07	1.38	0.06	7.07 ± 0.06

To conclude whether the difference in learning outcomes between the control and experimental classes is significant, we conduct an independent t-test and calculate the effect size (ES).

The results of summarizing the p value and ES value of the experimental class compared with the control class obtained the following results:

Table 6. Parameters featured in first test results

Parameters	**Test 1**	**Test 2**
p (independent t-test)	0.001	0.004
ES	0.79	0.72

All p values are less than 0.01, the difference in scores between the experimental and control classes in both tests is significant. The experiment process had a positive impact on the results of the experiment class. The results in experimental classes are higher than control classes. Thus, the proposed experimental measures have helped develop the critical thinking competence of students.

The effect size values of the two tests range from 0.7 to 0.8, they show the effect of the experimental measure at an average level.

**** Qualitative assessment results***

Ms. Nguyen Thi N, Cau Giay Secondary school said that: "Student can easily determine that the chemical properties of acetic acid are similar to those of ordinary acids, but choosing the reaction that can make the rocket fly is a clear manifestation of criteria: Generate ideas for implementation and create hypotheses about that idea. She believes that the element of " Give general comments and assessments the initial ideas" is difficult to achieve in this project. She shared: "Contrasting with themself is quite difficult, especially for middle school students. When you think again, this is the turning point in your thinking, you will see your competence best in this step".

Besides, Ms. Nguyen Thanh H, Cau Giay Secondary School said: "The use of project-based learning has helped the students to participate actively and initiatively. Once they had ideas, students showed their interest in the project by voluntarily searching for relevant information. Students need to consider and verify to have the selective, accurate, and appropriate information." She shared that "After listening to the students' presentations, I see that finishing the products at home is not a difficulty for them. The children were quickly adapted to overcome the obstacles that arose to complete to the finished product".

3. Conclusions

Based on the study of a number of related documents, the article determines the structure of critical thinking competence and the rubric of criteria for assessing this skill. At the same time, the paper also identifies the process of developing critical thinking competence through project-based learning and applies it in the teaching project "Simple rocket design". The results in the criteria assessing sheet indicated that applying this process initially practice critical thinking skill for grade 9 students. Moreover, two tests' results which students at Cau Giay Secondary School participated in indirectly show the improvement in students' critical thinking competence. Therefore, schools can utilize project-based learning methods or flexibly apply several teaching methods to develop this competence; as well as apply the rubric to assess the progress of critical thinking development in students.

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