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ANALYSIS OF STUDENTS' CRITICAL THINKING SKILL OF MIDDLE SCHOOL THROUGH STEM EDUCATION PROJECT-BASED LEARNING

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ABSTRACT

This research is to investigate the students` critical thinking skill by using STEM education through Project Based Learning. The study applied descriptive research design. In these lessons, the participants were 160 first grade Japanese middle school students from four classes. They were divided into nine groups each class. The instruments are worksheets to explore students' initial knowledge about how to clean up wastewater and critical thinking processes. The worksheet consists of the designing solution, and understanding of concepts to identify critical thinking based on purpose and question, selection of information, assumption, and point of view the solution, and implication. Students were asked to design tools to clean up the wastewater. Students were given more than one chance to design the best product for wastewater treatment. The lessons consist of six lessons. The first lesson is the introduction of colloid, solution, and suspension, and discussion about wastewater. The second lesson to the fourth lesson was finding solutions and designing products. The fifth lesson was to watch a video of wastewater treatments in Japan and to optimize the solutions or products. The last lesson was to make a conclusion, to exchange presentations, and to develop discussion. Implementation of STEM education can be seen from the students` solutions, some students used biology or chemistry or physics or combination concept and Mathematics to design solution (technology) for treatment of wastewater. The result showed that the mean score of students` critical thinking skill was 2.82. The students` critical thinking skill was categorized as advanced thinker: 41.6%, practicing thinker: 30,6%, beginning thinker: 25%, and challenged thinker: 2.8%. And the category for students` critical thinking was practicing thinker. Practicing thinker is a stage of critical thinking development, they have enough skill in thinking to critique their own plan for systematic practice, and to construct a realistic critique of their powers of thought to solve the contextual problem.

Keywords: STEM, Project-Based Learning, Critical Thinking

INTRODUCTION

According to predictions, the job in STEM (Science, Technology, Engineering, and Mathematics) sectors will increase in the next decade more than jobs in other sectors. Therefore, the importance of STEM education has been realized by academia, government, society, and industry (Bybee, 2010). In the future, the students possibly do not work based on their educational background. The role of education as basic-career advancement has been aimed in the international setting (Mayo, 2009). Therefore, STEM education could be a way to bridge the gap between education and required workplace of 21st-century skills.

According to data from the United State Department of Labor, the importance of STEM

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skills are problem-solving skills (ill-defined problem), system skills, technology and engineering skills, and time, resource, and knowledge management skills (Kuenzi, 2008; Jang, 2016,). In the 21st century, scientific experiments are not sufficient to improve students' 21st-century skills, but how to apply scientific concepts to design the technologies or products and solving problems is also required. The change of human life will be accompanied by the evolution of technology. Therefore, students have to be prepared for the future challenges. Scientific inquiry, scientific practices, and engineering practices are required to encourage students to be a citizen who can adapt to face new conditions and problems (Bybee, 2013).

In addition, students create and present project-based assignments outside of the traditional classroom (teacher-centered delivery of instruction to classes of students who are the receivers of information) that connect to what they learn to real world applications. STEM *Project Based Learning* (PBL) in school motivated low performing students to be more interested in studying hard in STEM fields and decrease the achievement gap (Breiner et al., 2012).

Critical thinking is one of the most important real-life skills. Where in Next Generation Science Standard (NGSS) mentioned that critical thinking and communication skills must be possessed by students for their future. Critical thinking is analyzing and evaluating thinking with a view to improve it, in another words, self-directed, self-disciplined, self-monitored, and self-corrective thinking. In critical thinking, there are six stages consist of unreflective thinker, challenged thinker, beginning thinker, practicing thinker, advanced thinking, and master thinker (Paul &Elder, 2008). Critical thinking refers to an ability to analyze information, to determine the relevance of information gathered and then to interpret it in solving the problems. It requires high-level thinking; involves the process of analysis, evaluation, reasonableness, and reflection (Jeevanantham, 2005). According to Paul & Elder (2008), there are 8 elements of thought namely: purpose, questions at issue, information, interpretations and interferences, concepts, assumptions, implications and consequences, and point of view. The intellectual Standards describe the criteria used to evaluate the quality of the critical thinking.

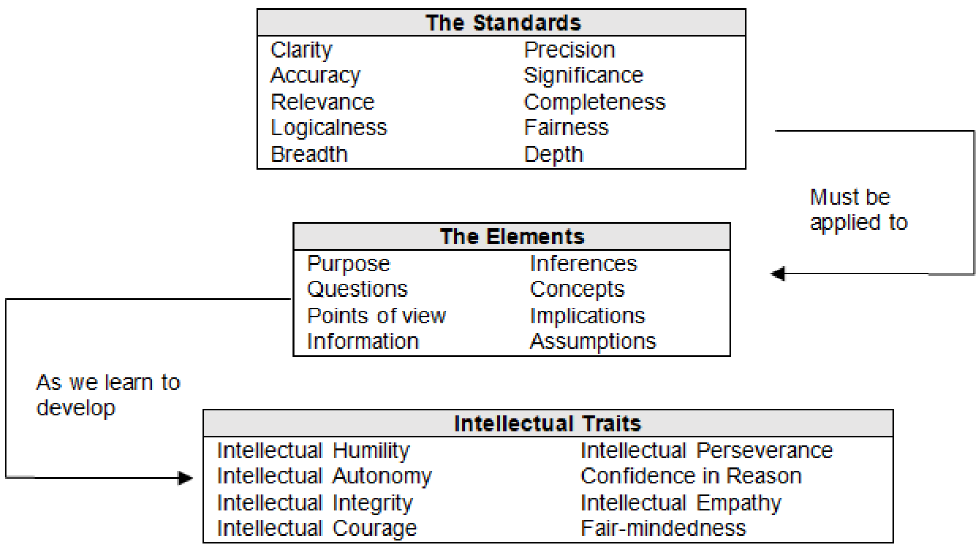

Figure 1. The Paul-Elder Framework for Critical Thinking (Paul-Elder, 2009).

Some researchers have reported that students in PBL taught classrooms improved critical thinking and problem-solving skills. Another researcher has also found that PBL has been a successful method of teaching 21st-century skills. Furthermore, students also have shown more initiative by utilizing resources and revising works, also students' behaviors were uncharacteristic before they were immersed in the PBL-instructed classes (Baron, et al., 1998).

Human beings can survive up to three weeks without food. In contrast, a lack of water is fatal within three to four days. This grim fact makes water disaster preparedness vital. Flooding, severe weather, earthquakes, and civil unrest can all interrupt public water delivery or introduce dangerously contaminates into your drinking supplies. Private well water may also be affected by floods, chemical spills, or similar catastrophes. A carefully thought out water disaster preparedness plan saves many lives.

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The research goals are to investigate students` critical thinking in STEM education through Project Based Learning that makes students more aware of the needs for clean water in the future (Stohlmann et al.,2012). Moreover, this research is not only to improve students' awareness and understanding of the needs of clean water, but also to improve students' critical thinking skills in their daily life (Gonzalez & Kuenzi, 2012). Therefore, students can apply what they learned at school to daily life problems or issues. The problem in this research is how students` critical thinking skills are developed through STEM education Project Based Learning.

METHODS

The study applied descriptive research design. Descriptive research is used to obtain information concerning the current status of the phenomena to describe the condition with respect to variables or conditions in a situation. Descriptive studies have an important role in educational research, they have greatly increased our knowledge about what happens in schools (Fraenkel &Wallen, 2006). Descriptive research can be either quantitative or qualitative. It can involve collections of quantitative information that can be tabulated along a continuum in numerical forms, such as scores on a test or the number of times a person chooses to use a certain feature of a multimedia program, or it can describe categories of information such as gender or patterns of interaction when using technology in a group situation (Knupfer & Hilary, 1966).

The participants were 160 first grade Japanese middle school students from four classes. They were divided into nine groups in each class. The instruments were worksheets to explore students' critical thinking skills how to clean up wastewater and problem-solving processes. Besides, the instruments were wastewater, filter paper, beaker glass, plastic bottles, litmus paper, and some materials or tools which needed by students (Williams, 2011). Therefore, students had to think the materials in order to solve problems.

In these lessons, students did not only wrote worksheets but also designed tools to clean up the wastewater. Students were given more than one chance to design the best product for wastewater treatment (Museus et al., 2011). The lessons consist of six lessons, the first lesson was the introduction of colloid, solution, and suspension, and discussion about wastewater. From the second lesson to the fourth lesson were to find solutions and design products.The fifth lesson was the video of wastewater treatment in Japan and optimize the solutions or products. The last lesson was to make a conclusion, presentation, and discussion. The lessons were started by the explanation of different solution and colloid. Furthermore, the illustration of a problem about the need of wastewater system in our city to conserve the sea was displayed. Then, students were asked to find solutions to clean wastewater (Milgram, 2011).

The data were collected by worksheets and observation sheets during the lessons. Then, data were analyzed using critical thinking rubric that designed by (Paul &Elder, 2009, Uttal et al., 2012). Paul &Elder critical thinking framework was one of the frameworks used by some researchers to analyze critical thinking because this framework was general for engineering, natural science, social science, and linguistics. The collected data were analyzed using ANOVA in order to see different of critical thinking of each class.

Table 1. Critical Thinking Rubric (based on the Paul-Elder critical thinking framework)

Dimension	Score			
	4	3	2	1
Purpose and question	Clearly identify the purpose including all complexities of relevant questions.	Clearly identify the purpose including some complexities of relevant questions.	Identify the purpose including irrelevant and/or insufficient questions.	An unclear purpose that does not includes questions.

Information	Accurate, complete information that is supported by relevant evidence.	Accurate, mostly complete information that is supported by evidence.	Accurate, but incomplete information that is not supported by evidence.	Inaccurate, incomplete information that is not supported by evidence.
Assumption and point of view	Complete, fair presentation of all relevant assumptions and points of view.	Complete, fair presentation of some relevant assumptions and points of view.	Simplistic presentation that ignores relevant assumptions and points of view.	Incomplete presentation that ignores relevant assumption and points of view
Implications and consequences	Clearly articulates significant, logical implications and consequences based on relevant evidence	Clearly articulates some implications and consequences based on evidence.	Articulates insignificant or illogical implications and consequences that are not supported by evidence.	Fails to recognize to generates invalid implications and consequences based on irrelevant evidence

Scores from critical thinking rubric were compared with criteria of critical thinking development based on stages of critical thinking development (Table 2)

Table 2. Scoring of Critical Thinking Development Stages (Paul and Elder, 2009)

Criteria of score:	3.51	-	4.0	:	Master Thinker
	3.11	-	3.50	:	Advanced Thinker
	2.41	-	3.10	:	Practicing Thinker
	1.71	-	2.40	:	Beginning Thinker
	1.01	-	1.70	:	Challenged Thinker
	0	-	1.0	:	Unreflective Thinker

RESULTS AND DISCUSSION

STEM Education through Project Based Learning

STEM learning through Project Based Learning was developed by NGSS (Next Generation Science Standard) framework. In this study, the lessons consisted of six lessons, the first lesson was the introduction of colloid, solution, and suspension, and discussion about wastewater. The second lesson to the fourth lesson was to find solutions and design products. The fifth lesson was to watch the video of wastewater treatment in Japan and optimize the solutions or products. The last lesson was to make a conclusion, presentation, and discussion. Each learning process was described in the following table 3.

Table 3. STEM Lessons

Activity	Crosscutting Concepts	Scientific and Engineering Practices (NGSS Framework)	Disciplinary Core Ideas
First Lesson			
Introduction of the theme of lessons and dividing the groups. (9 groups)			

Provide students to mention examples of solid, liquid, and gas (state of matter) in their daily life. (**Physics**)	Molecules pattern of solid, liquid, and gas. (CCs 1)	Asking questions and defining problems. (SEPs 1)	**Structure and Properties of Matter** The fact that matter is composed of atoms and molecules can be used to explain the properties of substances, diversity of materials, states of matter, phase changes, and conservation of matter. (PSs 1.A)
Students observe the demonstration and determine the colloid. (**Chemistry**)	Pattern, Cause and Effect, Scale. (CCs 1, CCs 2, CCs 3)	Asking questions and defining problems. (SEPs 1) Engaging in argument from evidence. (SEPs 7)	
Teacher introduce wastewater treatment plant/cleaning water system and asks students to find any information about how to clean wastewater. **Science**-discussing water pollution and which science concept is suitable to solved the problem. **Technology**-the solution **Engineering**-process designed solution. **Mathematics**-measure of amount the material.	The matter is conserved because atoms are conserved in physical and chemical processes. (CCs 5)	Constructing explanations and design solutions. (SEPs 6)	Type of Interaction Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. (PSs 2.B)
Students search information in internet, books, and so on.			

Second, Third, and Fourth Lesson

Students design wastewater treatment system. Students determine what they need to clean wastewater. Students check water clarity by their eyes. **(Science, Technology, Engineering, and Mathematics).** Students check pH before and after cleaning processes. Students redesign the wastewater treatment system. **(Science, Technology, Engineering, and Mathematics).**	Influence of science, engineering, and technology on society and the natural world. (CCs 7)	Asking questions and defining problems. (SEPs 1) Developing and using models. (SEPs 2) Planning and carrying out investigations. (SEPs 3) Analyzing and interpreting data. (SEPs 4) Using mathematics and computational thinking. (SEPs 5) Constructing explanation and designing solutions. (SEPs 6) Engaging in argument from evidence. (SEPs 7)	Defining and delimiting engineering problems. (ETSs 1.A) Developing possible solutions. (ETSs 1.B) Optimizing the design solution. (ETSs 1.C)

Fifth Lesson			
Students watch the video about wastewater treatment plant. Students redesign wastewater treatment by drawing or if the time is available, students can redesign their prototype. **(Science, Technology, Engineering, and Mathematics).**	Influence of science, engineering, and technology on society and the natural world. (CCs 7)	Developing and using models. (SEPs 2) Planning and carrying out investigations. (SEPs 3) Analyzing and interpreting data. (SEPs 4) Using mathematics and computational thinking. (SEPs 5) Constructing explanation and designing solutions. (SEPs 6) Engaging in argument from evidence.(SEPs 7)	Defining and delimiting engineering problems. (ETSs 1.A) Developing possible solutions. (ETSs 1.B) Optimizing the design solution. (ETSs 1.C)
Sixth Lesson			
Students present and explain their prototype of wastewater treatment system (concept, before and after treatment, and material used). **(Science, Technology, Engineering, and Mathematics).**	Influence of science, engineering, and technology on society and the natural world. (CCs 7)	Obtaining, evaluating, and communicating information. (SEPs 8)	Defining and delimiting engineering problems. (ETSs 1.A) Developing possible solutions. (ETSs 1.B) Optimizing the design solution. (ETSs 1.C)

Analysis of Students` Critical Thinking

Collected data from the worksheets involved design solutions, results, and conclusions. The problems defined by students was almost same, which was `how to clean wastewater before moving to the sea because if the sea dirty, it would damage the environment`. Some examples of students' design solution can be seen in table 4. Most of the students had ideas about distillation and filtering system to clean the wastewater.

According to students` worksheets, some of the groups cleaned wastewater using simple distillation system or boiling. However, students realized that boiling consumed more energy and could not be an efficient solution. In this case, students evaluated their solution, it meant indicating that they had critical thinking skills. Furthermore, students used euglena to clean wastewater. Unfortunately, the results were unexpected, wastewater was still dirty. Based on their experiment results, they thought that distillation method could clean wastewater and use Euglena would not contaminate the environment. Finally, students concluded that the combination of distillation and euglena would be an effective, efficient, and environmentally friendly solution. According to these statements, students were still lack of logical thinking and made a conclusion from the data. Distillation used heat for boiling the water, so it could not be an efficient solution.

Another one of the samples of students' solution was evaporation. They provide 3 samples of wastewater and each sample was boiled in different length time. Their thinking was a similar researcher and they tried to investigate the result based on length time of boiling. However, they did the experiments in an opened condition. So, the clean water would go to atmosphere. Even though 15 minutes boiling showed the cleanest result than others pH of wastewater was most acidic than others. According to this, 15 minutes boiled sample was not fresh water, because the range of pH was too large. If this acid water goes es to the sea, it would make the sea be acidic. They did not analyze and evaluate the data, it means that they lack in critical thinking skill.

Table 4. Students` Design Solution and Classifying Stages of Critical Thinking.

Design Solution	Result	Conclusion	Stage CT
Boiling wastewater in an isolated system will keep water in the system. S: physic T: evaporation kit E: design evaporation kit from beaker glasses (small and big). M : not used	Dirty water became clean, but it consumes much time.	Boiling water is effective method to clean water.	Challenged Thinker (Lower Thinker)
Biological Using water (microorganism) from turtle pond (surface, middle, bottom), and leave for one day, after that stir the wastewater. Avoid the sunlight. S: biology and physic T: cleaning system using micro organism E: design bath of biological cleaning system. M: not used	No significant difference of each sample, but after being stirred, the sample became little clean.	Stirring was needed for better result. Pond water did not work to clean wastewater. Perhaps, there no microorganism who can clean the water.	Beginning Thinker (Average Thinker)
Physical filtering 1st experiment used filter paper, stone, leaf, and charcoal. 2nd experiment did not use leaf. 3rd experiment did not use filter paper. S: physic T: filtering kit E: design filtering system by various materials. M: not used	1st experiment: the water was clean. 2nd experiment: the result was not different from 1st experiment. 3rd experiment: after two times filtering, the water became clean.	The leaf does not the role of the cleaning system, but filter paper has it.	Practicing Thinker (Average Thinker)
Distillation Identify effectiveness based on volume of samples 10 ml, 20 ml, and 30 ml. Biological system (using euglena). Mix pond water and sample, and then store for a day. S: physic and biology T: distillation kit E: design distillation kit from tubes, pipe, and rubber stopper. M:calculate the volume of sample	Distillation: the water became clean, but consumed energy. Using Euglena: no change anything, but environmental friendly.	The combination of distillation and using euglena would become effective and environmental friendly solution.	Advanced Thinker (Higher Thinker)

These worksheets were analyzed using critical thinking rubric (Table.1) and the result of critical thinking of each group in all classes is shown in figure 1.

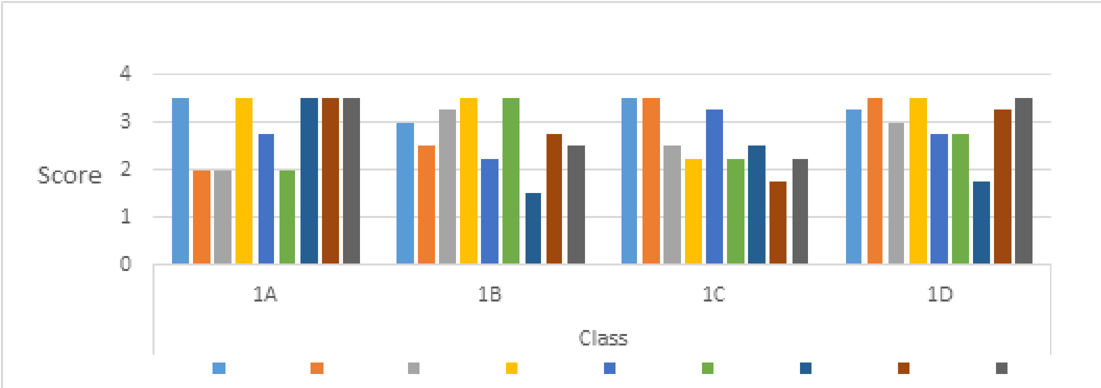

Figure 1. Score of Critical Thinking

Based on measures Tukey test, the mean scores of critical thinking skill for each class can be compared in order to see a significant difference. The result shows that the mean critical thinking score for class 1A was 2.92 (SD 0.72); 1B was 2.75 (SD 0.65); 1C was 2.67 (SD 0.62); 1D was 3.03 (SD 0.62), and mean score of critical thinking all of the students was 2.82. The highest students` critical thinking skill is class 1D, and the lowest is 1C. There was significant with the reports of the Tukey multiple comparisons for the critical thinking score.

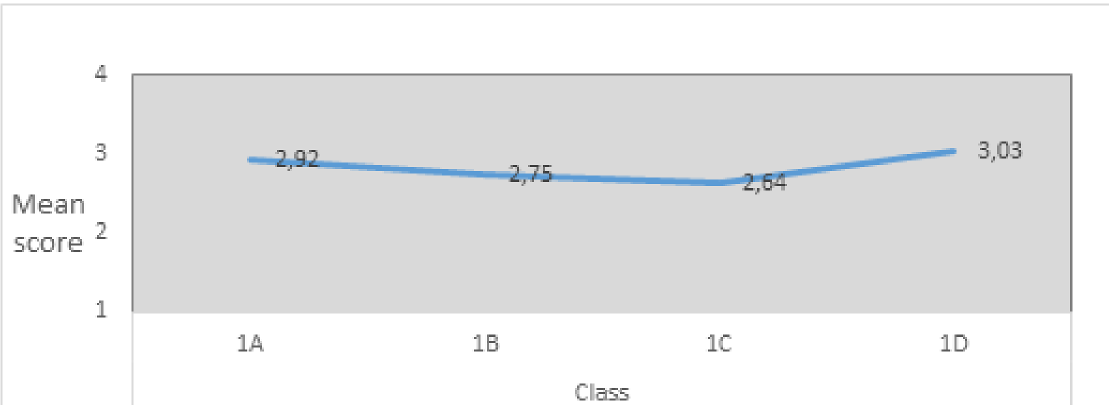

Figure 2. Critical Thinking Skill's Mean Scores

Table 5. Tukey Multiple Comparison of Critical Thinking Score

(I) CLASS		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1A	1B	.16667	.30979	.949	-.6727	1.0060
	1C	.27778	.30979	.807	-.5615	1.1171
	1D	-.05556	.30979	.998	-.8949	.7838
1B	1A	-.16667	.30979	.949	-1.0060	.6727
	1C	.11111	.30979	.984	-.7282	.9504
	1D	-.22222	.30979	.889	-1.0615	.6171

1C	1A	-.27778	.30979	.807	-1.1171	.5615
	1B	-.11111	.30979	.984	-.9504	.7282
	1D	-.33333	.30979	.706	-1.1727	.5060
1D	1A	.05556	.30979	.998	-.7838	.8949
	1B	.22222	.30979	.889	-.6171	1.0615
	1C	.33333	.30979	.706	-.5060	1.1727

In order to determine of q score of Tukey test, q calculate is mean difference divided by the standard error. Furthermore, q critical can see from table q score in which k (number of class) is 2, df (number of data – k) is 16. The calculation to determine the significance of difference can be seen in table 6. According to the calculation of Tukey test, the score of critical thinking skill of each class shows no significant among students` performance, because of q_{cal} is lower than $q_{critical}$ (Hochberg, 1987). It means that the learning processes of each class were the same, so critical thinking skill of students in each class no gap at all.

Table 6. Significance Difference of Each Class

Class	Q calculate	Q critical (alpha = 0.05)	hypothesis
1A – 1B	0.539	3.00	No different significantly
1A – 1C	0.897	3.00	No different significantly
1A – 1D	0.181	3.00	No different significantly
1B – 1C	0.358	3.00	No different significantly
1B – 1D	0.716	3.00	No different significantly
1C – 1D	1.074	3.00	No different significantly

Critical thinking score compared d with criteria of critical thinking development based on the stage of critical thinking development (Table 2.). Categories of students` critical thinking skill were an advanced thinker (41.6%), practicing thinker (30.6%), beginning thinker (25%), and challenged thinker (2.8%). In simple word, challenged thinker included in lower thinker, beginning and practicing thinker included in average thinker, and advanced thinker included in higher thinker (figure 3).

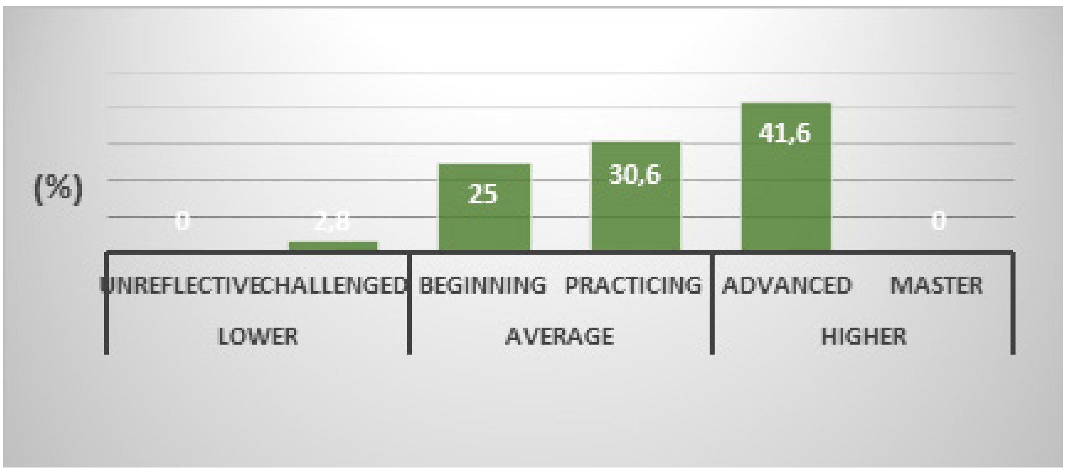

Figure 3. Stage of Critical Thinking (%)

Unreflective thinkers and challenged thinkers included in lower thinker. The finding indicates that only 1 group had lower thinker stage of critical thinking. Lower thinkers had very limited skills in thinking, they only focus ed on one solution, and they did not try to give better solutions. As shown in Table 4, lower thinkers` design solution was simple isolated cleaning wastewater isolated evaporation system kit from beaker glasses. There was no separation between clean water and wastewater. The lower thinker group conducted one experiment only and they did not evaluate at all. Whereas learning activities were conducted in 6 lessons, it was possible to evaluate their experiment. However, they may have developed a variety of skills in thinking without being aware of them, and these skills may serve as barriers to the development. At this stage of critical thinking with some implicit critical thinking abilities may deceive themselves easily into believing that their thinking was better than what actually was, they were making it more difficult to recognize the problems inherent in poor thinking (Paul & Elder, 2008).

Average thinkers have 2 stages of critical thinking, there were beginning thinker and average thinker. Thinkers at this stage had a sense of the habits which they needed to develop to take charge of their thinking. Base on Table 4, average thinkers` design solutions were cleaning wastewater system by filtering kit. They tried some experiments to get a better solution. This method was effective to clean water, but it was not efficient. In engineering solution, efficiency and effectiveness must be concerned. However, since average thinkers only began with to approach the improvements of their thinking in a systematic way. Average thinkers had enough skills in thinking to critique their own plan for systematic practices and to construct a realistic critique of their powers of thought (Paul & Elder, 2009). Furthermore, average thinkers had enough skills, to begin with regularly monitor their own thoughts. Thus they could effectively articulate the strengths and weaknesses of their thinking. Practicing thinkers could often recognize their own egocentric thinking as well as egocentric thinking on the part of others (Paul & Elder, 2008).

Table 7. T-test between Mean Scores Lower-Average-Higher Thinker

	Test Value = 0					
	t	df	Sig. (2-tailed) P_{value} = ½ Sig	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Score (lower-average)	25.092	19	.000	2.32500	2.1311	2.5189
Score (average-higher)	27.700	34	.000	2.85714	2.6475	3.0668

Advanced thinkers (higher thinker) regularly critiqued their own plan for systematic practices, and improve it thereby and had established good habits of thought which were "paying off". As shown in Table 4, higher thinkers` design solution was cleaning wastewater system by combining 2 methods, biological and distillation kit. They tried various methods and combined the methods to get best solutions. The combination of distillation and biological would become effective and environmentally friendly solutions. Based on these habits, advanced thinkers not only analyzed their thinking in all the significant domains of their lives but also had significant insights into problems at deeper levels of thought. While advanced thinkers were able to think well across the important dimensions of their lives, they were not yet able to think at a consistently high level across all of these dimensions. Advanced thinkers had good general commands over their egocentric nature. They continually strived to be fair-minded and sometimes lapsed into egocentrism and reason in a one-sided way (Paul & Elder, 2008).

T-test was used to determine significant differences between mean score lower thinkers-average thinkers, and average thinkers-higher thinkers. Table 7 reports there are significant differences between mean lower thinkers and average thinkers (Pvalue< 0.05). Also, base on table 7, there are significant differences between mean average thinkers and higher thinkers (Pvalue< 0.05). Overall, the findings of differences between mean score lower thinker-average thinker-higher thinker suggested that STEM learning through Project Based Learning could differentiate between lower thinker, average thinker, and higher thinker.

CONCLUSION

This study has achieved its objectives. The study aims to investigate students` critical thinking skill in STEM education through Project Based Learning. The result showed that mean score of students` critical thinking skills was 2.82. Percentages of students` critical thinking skill were the advanced thinker (higher thinker) 41.6%, practicing thinker (average thinker) 30,6%, beginning thinker (average thinker) 25%, and challenged thinker (lower thinker) 2.8%. And the category of students` critical thinking was the average thinker. Average thinker was a stage of critical thinking development, they have enough skill in thinking to critique their own plan for systematic practice, and to construct a realistic critique of their powers of thought.

The present study has some limitations that need to be taken into account when considering the study and contributions. The participants in this study were self-selected based on random distribution, there was no arrangement in the division of the groups. The division of group should consist of higher thinker who can be a leader to guide lower thinker.

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