

Implementation of Authentic Learning and Assessment through STEM Education Approach to Improve Students' Metacognitive Skills

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ABSTRACT

The important aspects of improving metacognitive skills are knowledge, intelligence, experience, and practice. STEM education is considered to be one of the most influential approaches to encouraging students to be self-regulated learners. In STEM education lessons, students are provided many opportunities to develop their thinking skills (metacognitive skills, critical and creative thinking). The goals of this study were to identify the effects of STEM education in the improvement of metacognitive skills, and to investigate metacognitive activities in STEM education. The participants were middle school students in the third year. The research instrument was the Metacognitive Activities Inventory (MCAI), used to identify changes in metacognitive skills before and after the lessons. Furthermore, portfolios were used to record students' learning processes and help them reflect on their thinking and the tasks. The results show no significant changes in metacognitive skills. However, STEM education engages students in metacognitive activities. Therefore, implementation of STEM education in the classroom provides opportunities to students for understanding the importance of the integration of different disciplines and its applications. In addition, STEM education can increase students' interest in science lessons.

Keywords: STEM education, metacognition, authentic learning, authentic assessment

Introduction

Decreasing enrollments and numbers of students graduating in science and technology fields in several European countries, as well as Australia, Japan, and the United States have been cause for concern at the national level because without science and technology, the economic condition of a country cannot develop well (Gonzales & Kuenzi, 2012; Kearney, 2011; Osborne & Dillon, 2008; Queensland Department of Education, Training, and the Arts, 2007). The Next Generation Science Standard (NGSS) developed by the U.S. government is the new framework in science education that provides opportunities to improve the quality of science education and student achievement (NGSS, 2013).

The vision of NGSS emphasizes that science education must provide challenges for students in three dimensions, namely science and engineering practices, crosscutting concepts, and disciplinary core ideas (NGSS, 2013). Therefore, the new challenge for teaching and learning in science is how teachers can plan and manage science lessons that combine science and engineering practices, crosscutting concepts, and disciplinary core ideas. The expectation is that students will achieve meaningful and sustainable learning as a result.

STEM education is one innovative approach in science learning. STEM education is similar to Science and Technology in Society (STS), although engineering processes are not explicitly emphasized in STS. The similarity of STEM and STS is the necessity of use of scientific processes by students in the classroom (Bybee, 2013; Yager, 1996). Based on the characteristic of STEM education of focusing on design solutions for real world issues and

problems, a STEM education approach is one way to conduct science and engineering practices combining several strategies that provide implementation of crosscutting concepts and core disciplinary ideas in science lessons. Moreover, STEM education is a tool for helping students become STEM literate (Bybee, 2013; Kearney, 2011).

STEM education activities involve scientific processes and engineering design. Scientific processes are a methodological approach to the process of inquiry in which empirically grounded theories of nature are constructed and verified (Betz, 2011). Scientific processes occur naturally and spontaneously in our minds. By logically breaking down the steps of our thinking, we can use scientific processes to find out how to answer questions about how the world works. Scientific processes are not only useful in science, but also any situation that requires critical thinking. Scientific process skills involve observing qualities, measuring quantities, sorting and classifying, inferring, predicting, experimenting, and communicating (Vitti & Torres, 2006).

In order to conduct science and engineering practices, what are the important skills that students must possess? Metacognitive skills provide strategies to conduct science and engineering practices effectively and efficiently. Metacognition is a set of higher-order thinking skills that help students find the best solution to a problem (McGregor, 2006). Furthermore, many experts in education and educational studies have suggested that metacognitive skills affect students' learning strategies, allowing them to achieve meaningful learning and encouraging them to become lifelong learners.

Metacognitive skills can be improved through concept maps, complex learning of unfamiliar problems and issues, taking notes, discussion, and scaffold instruction (Huang, 2012; Sharifi, 2012; Doyle, 2013; Paulsson & Mayer, 1991; Molenaar *et al.*, 2011; Jelinek *et al.*, 2013; Van Der Stuyf, 2002). STEM education is one form of complex learning that emphasizes practices in learning, where practices are the innovative steps of complex learning that must be supported by metacognitive skills (Van Merriënboor & Kirschner, 2007).

The goals of this study were to investigate the effects of scaffolding instruction, portfolios, and argumentation within a STEM education framework in improving students' metacognitive skills, and to investigate science and engineering practices and the efforts of students to produce technology. The questions of the study are whether scaffold instruction and portfolios improved students' metacognitive skills, and how students made use of skills and effort in producing technology.

Scaffold instruction helps students determine the logical steps needed to reach a goal, while portfolios help students reflect on and evaluate their thinking, and then monitor and plan their activities and knowledge. Discussion allows students to share ideas and thinking, which can become a medium for reflection and evaluation of their own thinking. Furthermore, STEM education is an approach to teaching scientific and mathematic applications through engineering activities that involve the development of technology. Therefore, the combination of scaffold instruction, portfolios, and discussion within a STEM education framework will improve students' metacognitive skills.

Methodology

This study was conducted at the middle school level. The participants were four classes of third-year middle school students. Each class was divided into ten groups of four or five students, with the requirement that each group there must have female student(s). Each class had three lessons with the same instruction. This lesson was project based learning, so thinking skills and performances were needed to find a solution. In fact, students did find a solution in different ways.

Two science teachers who had teaching experience of more than 10 years conducted these lessons. Each teacher taught two classes. The lessons were conducted during the first semester and were about magnetism, electricity, and electrical energy. The electricity energy concept had been introduced to students the previous year. These concepts were needed to understand energy concepts in the second semester. Therefore, the learning environment forced students to correlate existed knowledge and new knowledge. This learning process is one of metacognitive activity.

The problem of the lesson sequence related to real world activities, in which motors have many functions in vehicles and other machines. The students were asked to make a DC motor that was faster, more stable, more efficient, or cheaper. They had to decide what kind of motor was needed. Therefore, students designed solutions based on their goal (goal orientation is a metacognitive skill). In the design process, students must think about a given budget to buy the parts of the DC motor and conduct several trials (like scientists and engineers have to do).

For this research, students completed the pre- and post- Metacognitive Activity Inventory (MCAI) questionnaire individually. The MCAI consisted of 27 questions that ask about the frequency (always, sometimes, never) of specific metacognitive activities, which were translated into Japanese. MCAI questionnaire was given to identify metacognitive activities that are usually performed when students solve a problem (Cooper & Sandi-Urena, 2008). Questions 1 to 19 are positive statements, while items 20 to 27 are negative statements. The positive statement "always" was scored as 5 points, "sometimes" 3 points, and "never " 1 point. For negative statements, the scoring was opposite of positive statements.

After students filled out the MCAI questionnaire, another questionnaire about DC motors was given to students. These consisted of questions such as: *Have you ever disassembled a DC motor?; Please mention all of the parts in the DC motor; and What kind of transformation energy occurs in a DC motor?* Research materials included worksheets, electrical tools (voltage and current tester, batteries, coated wire), the separate components of the motor (rotor, motor case, wire, terminal, gear, coil), and other materials (circuit, cutter, stopwatch, sandpaper).

To begin, the teacher introduced how the motor works based on magnetic theory, and students identified how to utilize motors in many technologies and the benefits and problems of electrical and gasoline cars. Furthermore, students were provided limited money to buy parts for the motor: three wires with different diameters, a volt meter, and ampere meter.

Students measured the current and voltage of each battery (alkaline and Ni-MH batteries) and the different diameters of wire (0.32mm, 0.4mm, and 0.5mm). This activity is a type of scaffold instruction. The reasons for measuring the electrical current and voltage were not explained to students. Hopefully, students could understand the reason of measuring ampere and voltage after comparing the differences of the motor designs using different wires. Furthermore, students discussed the parts of the motor that they needed to buy. During this time, students engaged in discussion within the group based on the data of amperes and voltage. Debate is important in sharing thinking and ideas based on scientific evidence (Hand *et al.*, 2009).

In debate and discussion, students have a chance to share and learn new knowledge and reflect on the ways other students think. Because these lessons could not be finished in one class time, students were given chance to inquire about conceptual, contextual, and technical information relating to motors and batteries at their homes. During outside school

time, each student was required to make a portfolio to report the activity related to motor design and battery used.

Once the students had finished designing a motor, they tested the performance of the motor using a toy car on a circuit and recorded the speed of the toy car. In this step, students identified problems, and evaluated their product. This activity provided students an opportunity to redesign the solution or change the goal. In the last lesson, students concluded what they have learned from these lessons with emphasis on energy, electricity, electrochemistry, and motion concepts.

To assess students' performance, the learning processes of each group, recordings by video camera and sound recorder, notes from observers, and students' portfolio were analyzed qualitatively, and the MCAI questionnaire results were analyzed quantitatively using T-tests to investigate the differences between mean pre- and post-questionnaire for each question (Hinkle, Wiersma, & Jurs, 1988). Many methods of recording were used to avoid not recording any of the processes of learning and to provide material for formative assessment (Dodge, 2009). In science lessons, assessment of learning processes is important in improving student performance. Teachers can use it to reflect methods and strategies to improve their instruction. Some methods in these lessons involve portfolio, discussion, debate, and scaffolding in order to improve metacognitive skills of students (Cakan, *et al.*, 2010; Molenaar, 2011; Falk & Brodsky, 2013).

Results and Discussion

The data were collected over several weeks, and each class needed three lessons, or five to six hours to finish the sequence. In the lessons, most students had difficulty making the motor (designing it rather than constructing it). Designing the motor means making it using the rotor and wire, while constructing the motor means making it using the coil (pink wire). Students needed 10 minutes to fill out the MCAI questionnaire because they needed to think about their habits when they encounter a problem. The contents of the MCAI questionnaire consisted of questions about habits during problem-solving activities.

Beside the MCAI questionnaire, students had to fill out a questionnaire about their experience with DC motors. Around 50% of the students had disassembled a DC motor in second grade. Furthermore, questions about the transformation of energy in the DC motor resulted in the following: 40.6% of the students answered electrical to kinetic energy; 39.1% did not know; 13.3% answered kinetic to electrical energy; and 7% answered electrical energy to kinetic, heat, and sound energy. Not all students who knew about energy transformation concepts had experience disassembling a DC motor. The concept of energy transformation is taught to third-year students in the second semester, so many students still did not understand the forms of energy.

MCAI questionnaire

Metacognition is important to decide the effective and efficient solution. In order to decide solution, students need to think deeply weakness points and strength points of that solution. Therefore, the results of pre-questionnaire show students' work in first attempt solving problem.

The results of the MCAI showed that for the positive statements in the first to the nineteenth question, students always did the activities on average. Average scores for positive statements (questions 1–19) ranged from 3.11–4.71 on the pre-questionnaire and 2.94–4.71 on the post-questionnaire. Furthermore, for the negative statements (questions 20–27) have mean scores ranged from 1.81–3.63 on the pre-questionnaire and 1.76–3.69 on the post-questionnaire.

Generally, students gave higher ratings to Question 4 ("Once a result is obtained, I check to see that it agrees with what I expected"). This means that students wanted to try again if the result did not satisfy them. This evidence correlates with process learning in STEM lessons. When students designed the motor successfully, but the car did not move or ran slowly on the circuit, they tried to identify the failure and wanted to try to improve performances. Moreover, students change the goal of manufacturing a motor after they got other problems (consume more energy, overheat, and go out from circuit). Students redesign the fast motor to be safety motor using thinner wire. In these activities, students were recognized that thicker wire makes motor run rapidly, so they were used thin wire to solve generated problems.

However, the lowest rating on the MCAI was Question 27 ("During practice, if a problem takes several attempts and I cannot get it right, I get someone to do it for me and try to memorize the procedure"). This means that students easily gave up when they faced a difficult problem, and then they asked other students or the teacher to do it until there was success because they wanted to find the correct procedure. After this success, they tried to do it by themselves. In other words, students made no effort to think deeply and preferred to memorize everything. According to the teachers and the principal, most students in this school had the attitude revealed in Question 27.

Table 1. Calculation of Pre- and Post-Questionnaire for all Third-Year Students.

Variable	Value	Mark
Number of students	147	t calculated at less than the value at alpha 0.1, which means the null hypothesis was confirmed (not significant).
SUM Gain	160	
SUM Gain ²	9430	
Std. Deviation (s)	7.962	
Normal Gain (t)	0.657	
t alpha 0.1	1.671	
t alpha 0.05	2.000	
t alpha 0.01	2.660	

The null hypothesis was confirmed, which means there were no significant differences between the pre- and post-MCAI questionnaire for all third-year students (Table 1). Nevertheless, the means for pre- and post-MCAI show differences in scores. According to an analysis of mean scores of each question on the MCAI, it was found that students did most of the activities listed on the questionnaire, which indicates that they already had good metacognitive skills. This cannot be analyzed as resulting from the lesson because there were no significant differences. However, when responses were analyzed individually, there were several students whose attitudes toward the statements changed after the lesson.

Students' Design Processes

The worksheets involved measuring voltage and amperes, listing parts, design (explanation of reasons for using each part), and recording time and differences between the two batteries. Not all groups filled out the worksheets completely, but the worksheets adequately represented the attitudes and skills of the students. It is mean that not all students can work together in a group.

In scientific experiments, students need to measure more than once to gain the reliability of the data. If students are inaccurate in measuring and generate inaccurate data, this can lead to misconceptions in their beliefs. According to some teachers' information and observations of elementary school lessons, students need to understand that electrical current flows more easily through a thick wire than a thin one (lesson study at Shizuoka University Attached Elementary School Hamamatsu in 2011). This evidence shows that students do not apply initial knowledge and experience to a new context. Therefore, students do not have awareness of their cognition. Students need this kind of skill in the future to make the best decisions in solving problems and issues. This activity is a metacognitive activity, where levels of metacognitive awareness in the first level coordinate with experience and knowledge in the new context of the fourth level (McGregor, 2006).

Most of the students did not know that the wire that was provided was a coated wire, and that measuring it would generate incorrect data. In addition, students did not measure current and voltage under the same conditions. As a result, the teacher directed the students to measure current and voltage again. The teacher communicated with students using questions that guided them to scratch the wires and measure them under the same condition. This phenomenon is one of scaffolding in order to guide students' knowledge and practical skills. Measurement of wires and batteries is one example used in scientific inquiry, which illustrates inquiry generally done by scientists (Table 2).

Table 2 Measuring voltage and current of two batteries and three wires

Group	Properties	Alkaline Battery				Ni-MH Battery			
		No Wire	0.32	0.4	0.5	No Wire	0.32	0.4	0.5
A	Voltage (V)	1.5	1.5	1.5	1.5	1.4	1.5	1.5	1.5
	Current (A)	1.6	1.9	2.3	2.3	2	2	2.9	2.5
B	Voltage (V)	1.5	1.5	1.5	1.5	1.25	1.1	1.25	1.3
	Current (A)	4.5	4; 3.8	4; 4.1	5	4	3.2; 4.1	4.2	3.5; 5
C	Voltage (V)	1.5	1.5	1.5	1.5	1.3	1.3	1.3	1.3
	Current (A)	2.1	2.7	2.7	2.5	2.4	2.1	2.2	2

After measuring voltage and current for reference in selecting parts, students had to design a DC motor within a limited budget and write down all the parts needed and the reasons. These activities are one of example of engineering practices, where students design and redesign the motor until they are satisfied. Engineering design is divided into three levels based on difficulty (Haik & Shahin, 2011). **Adaptive design** is manufacturing a product with minor modifications, for example modifications in shape or size, materials, specifications, and so on. This design activity does not require special knowledge or skills, and solutions can be found easily. **Development design** requires more scientific training and design skills to create a new product. This level of design also starts from an existing product, but the new product is manifestly different from the existing one, for instance, the design of plasma and LED television based on traditional tube-based television. **New design** is the most difficult level because it requires mastery of previous skills, creativity and imagination, insight, and foresight. In this lesson, students were given learning tasks at the level of adaptive design, in which they needed to think logically to choose the best parts according to their design goal.

Most of the students argued that the thicker wire had less resistance, and that the electrical current would flow more easily through it. In measuring current and voltage, students calculated directly the amount of resistance of each wire because they thought that they needed wire with less resistance to design a quicker DC motor. Nevertheless, there was a misconception among the students about the correlation between the diameter of the wire and the electrical current or resistance. Furthermore, students stated that the thickness of the wire would not affect DC motor performance.

There are interesting accounts of students engaged in designing DC motors. Students developed misconceptions if they failed in a trial and did not confirm their results with other students or the teacher. This is one of the reasons for the importance of discussion and argumentation in the classroom because students can evaluate and reflect on their cognition and thinking through these processes (Erduran *et al.*, 2006; Hand, *et al.*, 2009; Jelinek *et al.*, 2013). Therefore, one of methods of improving metacognitive skills is discussion and argumentation (Jelinek, *et. al.*, 2013; Shen & Liu, 2011).

In the first example of how students designed a DC motor, a wire with greater diameter was used to generate greater speed based on smaller resistance and higher electrical current flow in the wire. Then students compared with the original coil (assembled by Tamiya). The motor rotated more rapidly, but it moved more slowly on the circuit (no power), while the original coil moved faster on circuit. As a result, students got the idea to design the coil using a thin wire in order to wind it more compared with a thick wire and fewer windings. Finally, they found evidence that the two kinds of winding (of the coil) were no different in terms of performance. As a result, they concluded that low resistance would generate low power. This conclusion differed from those of other groups that stated that a thick wire had low resistance and would generate greater power and speed. Finally, they checked several articles related to the design of a DC motor and concluded that according to electromagnetic principles (application of scientific concepts), a thick wire, an increased number of windings, and a strong magnet were needed to design a high-performance motor. However, they did not think about the heat (engineering).

Another interesting example is the fourth one (Table 3). Students tried to design a high-performance DC motor without problems. According to measurements of current and voltage, they found the thick wire better in terms of current and resistance. This result is parallel with their experiments in elementary school about differences between thick and thin wire regarding the flow of electrical current (scientific process). The thickness of the wire affected performance of the DC motor. They used thick wire to design the motor, but the terminal burned. Then they tried using thin wire to avoid burning the motor, but it did not work efficiently (moving and stopping). Then students determined that the motor did not have power, so they got the idea to increase the number of windings. In this lesson, a long wire was not provided, so students had to use lead and iron to connect two wires. Finally, they finished designing the motor, but it did not move. After that, they became aware that one wire was not scratched. They tried redesigning the coil until they produced the one that worked best (engineering process). Students had to use lead and iron to connect two wires. Finally, they finished designing the motor, but it did not move. After that, they became aware that one wire was not scratched. They tried redesigning the coil until they produced the best coil (engineering process).

The advantage of STEM education is that it improves knowledge and skills among students. Students redesigned the DC motor when they found a problem. They thought logically (with high levels of creativity and critical thinking) to solve problems and issues and identify the source of the failure. They found many solutions after each failure. This means

that they did not predict the disadvantages of each solution (lack of metacognitive skills). Nevertheless, the lesson was a good experience that improved their metacognitive skills.

Sometimes experiments create misconceptions among students that are beyond the control of the teacher. Some students need guidance or scaffolding to achieve meaningful understanding. The following is an example of a misconception arising from a student experiment that was beyond the control of the teacher.

今回分かったとは、銅線の抵抗の大きさです。0.4 mm < 0.32 mm < 0.5 mmとなりました。0.4 mm < 0.32 mm < 0.5 mmになるもの不思議です。次回は、電圧計と電流計を使って、一番抵抗のないものを購入したいです。

(Translation: What we learned this time was the amount of resistance of the copper wire. The results were 0.4 mm < 0.32 mm < 0.5 mm. We do not know why the result is 0.4 mm < 0.32 mm < 0.5 mm. We will buy the wire that has the lowest resistance).

This means that the 0.5 mm wire had greater resistance than the 0.32 mm and 0.4 mm wire, but the students reflected on and evaluated their understanding because they did not have evidence for that conclusion.

Table 3. Examples of Students' Logical Thinking and Misconceptions Regarding Design

Parts and Steps in Designing	Reason
Rotor, terminal, motor case, 0.5 mm wire, and gear Second attempt using 0.32 mm wire (1.5 m)	Thick wire has high efficiency in the transfer of energy. When motor uses 0.5 mm wire, trial was not successful and terminal was burnt, so we tried using thin wire. Motor sometimes stops and moves. This means there is no power; so further winding will improve the power. They used lead to connect two wires, but not successfully. As a result, the motor did not rotate. Also, they did not scratch the joined parts of the two wires.
Third attempt using two times 0.33 mm wire (3 m)	

Based on observations during the lessons, most students decided to buy a motor rather than make it, but they changed their decision after noticing other groups that were able to design a motor and car that ran faster than the original motor. As a result, all students tried to design their own motor in the next lesson. They found obstacles to designing a faster motor, such as shock current, slow speed and ease of overheating, but through scaffolding they were able to fix these problems.

Of 40 groups, 20 (50%) were successful at designing motors with different speeds; 19 (47.5%) completed their design of the motor but it did not rotate because of problems in the design of the coil, such as the fact that the wire was not scratched, some wires were not connected, and so on; and one group gave up on designing a motor and preferred to use a simple one because the members were all female and did not have experience with DC motors. This shows that experience and prior knowledge is important in improving other skills in learning (Dochy, De Ridjt, & Dyck, 2002; Hailikari, Nevgi, & Lindblom-Ylänne, 2007).

Learning Processes in STEM Education

Bransford, Brown and Cocking (1999) provide three suggestions regarding teaching and learning processes, as follows:

Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and

information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

The learning process is one important aspect in improving teaching and learning because it provides material for formative assessment. Formative assessment monitors the process of students' knowledge construction and progression toward the final product. It encourages students to achieve higher-order thinking skills (Lombardi, 2008). The following is a sample of students' arguments during the lessons.

One student in the group asked how to measure the current. They used a bulb lamp, and then discovered a problem with measurement, which was an electrical short. They communicated very well and worked together. After all measurements were finished, they started to think about how to make a motor at low cost. They discussed the wire (a thick wire for better current flow) and battery (Ni-MH for better power) based on measuring the wire (argumentation). Then they decided the parts needed to make the motor. They succeeded in making a motor on the first day. They needed less than one hour to make the motor, but it was low in power and speed, and easily overheated. In the next lesson, this group wanted to upgrade their motor to have greater speed. They discussed the budget more and then decided to rewind the coil. The students also discussed many problems with the motor such as the terminals and wire becoming burnt. One student said that this was because they used the Ni-MH battery, so motor rotation was too fast and some parts were burnt. Nevertheless, another student rejected her opinion. They wound the wire on the rotor more compactly to increase the number of windings. The motor rotated, but did not move on the circuit. They said that this would make the motor cheaper than the original.

According to the results of observations, most students felt excited during these lessons (STEM education approaches). STEM education provides students with knowledge and concepts that have relationships and applications in everyday life. Moreover, students can improve their logical thinking through engineering design processes based on scientific knowledge. Prior knowledge and experience is important in finding the best solution. The groups that had experience tended to be successful in designing a DC motor and made a good effort to finish and solve many problems.

In these lessons, many groups did not successfully design a faster motor. Therefore, there were students who understood the importance of balance in engineering design. For instance, students found many problems, such as the terminals becoming burnt, overheating, electrical shorts, and so on. In addition, they acquired scientific knowledge, for example, transformation of electrical energy into heat, sound, and kinetic energy; the fact that electrical current flows more easily through a thicker wire; the fact that a Ni-MH battery has low resistance; and the fact that thick wire has low resistance.

Conclusion

From the results of this study, it can be concluded that most of the students had good metacognitive skills from the average score for 1-19 questions. However, negative statements consist of easy to give up behavior in solving problem. The improvement in their metacognitive skills was not statistically significant. This showed that metacognitive skills cannot be improved significantly with one treatment, but it does not mean there was no improvement at all. Using questionnaire will generate inaccurate data, because students

aware that under observation, so there are possibilities that students answer the questions unnaturally (Cooper & Sandi, 2008). Using questionnaire is not recommended to measure abilities, intelligences, and skills.

Some students improve metacognitive skills based on observation of learning processes. Students improve their thinking, strategies, and creating of solutions through discussion and trial-error to solve problem. Furthermore, students enjoyed learning and communicated well in groups by posing questions to solve problems.

STEM education can attract students' interest in science lessons and provide them with a deep understanding of concepts and meaningful learning. Students can learn important scientific concepts (scientific knowledge), as well as their relationship and application in daily life. STEM education includes science and engineering practices (NRC, 2012). Therefore, students can do scientific research and engineering design at the same time. This is one of the advantages of STEM education.

STEM education not only increases students' interest in science lessons, but also improves their thinking and practical skills. Students can find design failures and then redesign until the product has a small risk of failure. In redesigning, students have to connect scientific knowledge and experience to the context to find the best solution, and then analyze the characteristics of the materials used.

Scaffolding during these lessons consisted of questions from the teacher that guided students to think more or to connect prior knowledge with the new context (problem). In addition, measuring voltage and electrical current can be identified as scaffolding that guided students to find solutions to problems. Students were able to reflect on and evaluate their thinking or solution when they encountered a failure. The notes made by the students helped them identify their knowledge, learning processes, and understanding. Therefore, students were able to monitor and evaluate their own understanding and thinking by themselves. This suggests that scaffolding can train students to improve their metacognitive skills. Therefore, we can identify scaffolding as a strong component of the portfolio.

Limitations of this study are using a questionnaire to investigate metacognitive skills for efficiency the time, however it is not an effective method to gain accurate data, so it authentic assessment is needed to assess students' skills. Observers not enough when compared to number of group in one class, so each group's activities cannot observe intensively. In concerning safety experiment, the motor can be very hot after running, nevertheless, no safety tools were provided to students.



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