Enhancement of STEM literacy on knowledge aspect after implementing science, technology, engineering and mathematics (STEM)-based instructional module

A Utami1*, D Rochintaniawati2, I R Suwarma3

1Departemen Pendidikan IPA, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung, 40154, Indonesia
2Departemen Pendidikan IPA, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung, 40154, Indonesia
3Departemen Pendidikan Fisika, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung, 40154, Indonesia

*Corresponding author’s e-mail: amairautami@upi.edu

Abstract. The scenario of 21st century relies heavily on the computer and digital system. Many scholars argued that the implementation of integrated science, technology, engineering and mathematics (STEM) in school system will have direct advantages for students, teachers and educational institutions. Therefore, this study is aimed to examine the enhancement of student’s STEM literacy on knowledge aspect after implementing STEM based module on earth’s structure and its dynamics topic. The method of this study was weak experiment pretest-posttest one group only. The subject of this research was one class of 7th grade students that consist of 32 students in one junior high school in Bandung, Indonesia. Developed STEM based module on earth’s structure and its dynamics topic was delivered to students. To measure students’ knowledge enhancement of STEM literacy, a pre-test and a post-test were given to students which consist of 20 multiple choice questions. Specifically, there are 11 questions of science literacy, four questions of technology-engineering literacy and five questions of mathematics literacy. Student’s pre-test and post-test result was analysed by calculating normalized gain and its effect size. The results of this research showed that students’ science literacy enhanced satisfactory (n-gain = 0.35) with 1.10 of effect size (strong effect), technology-engineering literacy shows the highest enhancement of (n-gain = 0.56) means that it also enhanced satisfactory with effect size score is 1.24 (strong effect), and mathematics literacy is the lowest enhancement of (n-gain = 0.32) and is categorized as satisfactory enhancement with effect size of 1.13 (strong effect). To sum up, student’s STEM literacy enhanced satisfactory with strong effect size after the implementation of STEM based module in their learning activity.

1. Introduction
The 21st century is the century of technology where everything relies on the computer system. This is where globalization and modernization era occurred along with technology and science development. Education also makes the great changes, teaching and learning activity for instance, is becoming more diversified and interesting which involve the advancement of technology in the entire school system.
Integrating Science, Technology, Engineering and Mathematics (STEM) gives advantages for students to connect the relevant skills learned to the use of the skills in the real world application by providing valuable learning contexts and help students to develop relevant knowledge and conceptual understanding [1]. The ability to identify, implement, and integrate concepts and contexts of Science, Technology, Engineering, and Mathematics (STEM) is known as STEM literacy which is to understand and solve problems that cannot be solved using one scientific discipline, but through innovative products [2]. STEM literacy has close relation with the demands of 21st century competencies and skills which would make students to be able to compete in new economic era and modernization in line with the demand of 21st century working skills. STEM literacy on the other hand is a relatively new idea that has not been well defined in literature or practice. The achievements in STEM literacy should cover students’ designing skill and all learning domains that referred to STEM as a whole. However, to be able to solve complex problems creatively and innovatively, students are expected to have identification, applying and integration STEM concept skills which are known as STEM literacy [3]. STEM literacy is characterized by the ability to use knowledge, skills and attitudes to solve contextual problem by applying various disciplines. In addition, engineering processes are also done by students to solve problems.

STEM education was initiated by the concern of students who were doubt to prepare their future career which demanded skillful workers whom integrate technology. By implementing STEM in school education, researchers and scholars believed that it would be useful for students’ future careers on engineering, science and technology by studying mathematics and science with the integration of technology and engineering [4]. Especially it is in Indonesia with the abundance of natural and human resources supposed to be a nation which implements technology development. However, the implementation of STEM education in Indonesia is still lack, not everyone recognizes it especially the research which proves the positive effects on implementing STEM at school.

In 2016, SEAMEO QITEP in Science did the research on the implementation of STEM in Indonesia to five schools in Bandung. The result shows that STEM-based learning has been implemented properly but there are several things need to be considered especially teacher’s skills, lesson plan (RPP) and learning resources such as modules, worksheets and books. Learning materials play a vital role in teaching and learning process at various level of education, it provides the opportunities for children to broaden and deepen their knowledge and understanding through scientific explanations of real-world phenomena and provide students opportunities to develop explanations of phenomena which could enrich student’s hard and soft skills [5,6]. One of instructional materials that is commonly used by teachers is module, the main function is usually helping students to cope with learning materials and to do some problems exercises related with the materials. Module is a kind of learning resource to help students understand specific materials learned at school by understanding the highlight and do the evaluation systematically to achieve the standard competence [7].

However, it is found that the majority of existing modules only meet the criteria of good module and it fails to meet the characteristics of STEM-based learning material especially in enhancing student’s STEM literacy because in average, existing module only meets two from six characteristics of great STEM learning materials. There are six characteristics of great STEM based learning material (1) Focus on real world issues and problems; (2) Guided by engineering design process; (3) Immerse hands-on inquiry and open-ended exploration; (4) Involve productive teamwork; (5) Apply rigorous science and mathematics content; (6) Allow for multiple right answers [8].

The main difference of STEM based module and existing module is basically on problem exploration and designing process which encourage active learning activity and make students easier to comprehend the materials. STEM based module is guided by engineering process design where hands-on activity and problem exploration is the main part of student’s activity which initiates active and meaningful learning process. There is an important consideration in developing successful STEM learning materials. The first is the “E” stands for engineering as the driving force behind STEM which what makes STEM different from regular science, technology and mathematics learning material. A good STEM-based learning material puts a heavy focus on engineering design process (EDP) which
leads to problem-solving approach. A framework of EDP based on basic technology education in Indonesia known as PDBU (Pikir, Desain, Buat Uji) [9].

This paper is purposely made to answer the call for the need of STEM based learning module which help students to prepare for real life and enable them to use knowledge and skills they need to be an informed citizen. To this end, the central research questions of this paper is developing STEM based module in learning earth’s structure and its dynamics topic to enhance student’s STEM literacy in knowledge aspect.

2. Methods
This study is a quasi-experiment study with one group pretest-posttest design [10] which was implemented in one secondary school in Bandung. Samples of this study consist of 32 students in one class of 7th grade which were given pretest and posttest before and after the implementation of STEM based module to measure the enhancement of student’s STEM literacy in knowledge aspect. STEM literacy was measured through 20 multiple choice questions which specifically consist of 11 science literacy questions, 5 mathematics literacy questions and 4 technology-engineering questions.

The STEM based Instructional material was developed based on the current Indonesia curriculum. Learning module contains STEM concepts on earth’s structure and its dynamics topic for 7th grader of secondary school students. Inside the module, each page has different focuses of Science, Technology, Engineering and Mathematics topic depends on what the page talks about.

Test instrument was developed based on Programme for International Student Assessment (PISA) for science and mathematics literacy questions, and National Assessment Educational Progress (NAEP) for technology engineering literacy questions. To measure student’s knowledge enhancement, the calculation of normalized gain <g> and its effect size were done and were interpreted according to its score [11,12].

The effectiveness of STEM-based module in improving students’ STEM literacy on knowledge aspect will be seen from the result of the normalized gain <g> that achieved by students during the learning process. For the calculation of the normalized gain <g> value and its classification will use equations [8] as follows:

\[
< g > = \frac{\%G}{\%G_{\text{max}}} = \frac{\%S_f - \%S_i)}{(100 - \%S_i)}
\]

Description:
\[< g > = \text{Normalized gain}\]
\[G = \text{Actual gain}\]
\[S_f = \text{Post-test score}\]
\[S_i = \text{Pretest score}\]
\[G_{\text{max}} = \text{Maximum gain possible}\]

| Score <g> | Classification |
|-----------|----------------|
| \(g \geq 0.7\) | High |
| \(0.7 > g \geq 0.3\) | Satisfactory |
| \(g < 0.3\) | Low |

3. Result and Discussion

3.1. Student’s Science Literacy
Science literacy questions consist of 11 questions of content knowledge and procedural knowledge aspects. The questions of science literacy on content knowledge were delivered in six questions number 9, 12, 13, 17, 18, and 19. Meanwhile the questions of procedural knowledge were delivered in five questions on number 1, 2, 3, 4 and 5. The recapitulation of the enhancement of science literacy based on two aspects is presented on Table 2.
Table 2. The Recapitulation of Science Literacy

| No. | Aspect                                      | N  | Pretest | Posttest | n-gain <g> | SD  | ES  |
|-----|---------------------------------------------|----|---------|----------|------------|-----|-----|
| 1.  | Content Knowledge:                          |    |         |          |            |     |     |
|     | Explain phenomena scientifically             | 6  | 36.52   | 60.02    | 0.37       | 27.12 | 0.87 |
| 2.  | Procedural Knowledge:                        |    |         |          |            |     |     |
|     | Interpret data and evidence scientifically   | 5  | 35.63   | 56.25    | 0.32       | 23.01 | 0.90 |
|     | Science Literacy                            | 35 | 35.55   | 58.30    | 0.35       | 20.65 | 1.10 |

According to the table 2, there is satisfactory enhancement of student’s understanding on science literacy after studying science by using STEM based module. Student’s normalized gain score reaches 0.37 on content knowledge which is classified as having satisfactory enhancement and 0.87 of its effect size classified as having moderate effect.

On the other hand, the result of science literacy on procedural knowledge aspect based on the calculation of n-gain score shows the score of 0.32 with the average of pretest and posttest scores are 35.63 and 56.25 respectively. The result of its effect size is 0.90. Therefore, the result of student’s science literacy on procedural knowledge shows moderate enhancement with moderate effect to student’s academic performance. Overall, student’s science literacy reaches the average normalized gain score of 35.55 from both content and procedural knowledge which has strong effect to students’ performance with its effect size score of 1.10. Student’s science literacy has moderately improved after the implementation of STEM based module, this is in line with a research done in developing STEM based module on Newton’s laws theory that student’s conceptual understanding on experiment class moderately improved while in control class with no use of STEM based module in learning process has slight improvement [13]. According to the result, student’s science literacy improved better on content knowledge compared to procedural knowledge aspect. It can be because first, content knowledge questions are asking student’s understanding regarding one particular topic which can be memorized and understood, while procedural knowledge questions are measuring student’s skill on interpreting data, figure, chart or scientific evidence. The task of procedural knowledge is almost always solving problems and the result measure is always accuracy, time and procedure [14-16]. These questions might be more challenging because if students cannot interpret data on the figure or chart, they would not be able to answer the questions although they understand the topic and memorized it well. Similarly, if students are able to interpret data but have no idea because they do not understand the topic, students will be failed in answering the questions. Conceptual knowledge is more consistently and strongly supports procedural knowledge [17]. Secondly, student’s conceptual understanding improved better on content knowledge compared to procedural knowledge because in STEM based module student’s content knowledge is trained better through quizzes, while their procedural knowledge especially in interpreting data is delivered only on page 12 and 13. Therefore, for future researchers, it is better to improve similar proportion of content and procedural knowledge.

Student’s science literacy is improving after the implementation of STEM based module, it is because, inside the module the four concepts of STEM is integrated followed by engineering design process activity. This integration will help students to improve their achievement in learning science [9,18]. Similarly, [19] revealed that engineering design process in learning science can help students understanding science concept better.

3.2. Student’s Technology Engineering Literacy

In this research, four questions of technology engineering literacy are delivered to students, three questions on understanding technological principle aspect on number 11, 15 and 16 and one question on developing solution and achieving goals aspect on number 10. The recapitulation of the enhancement of technology engineering literacy based on two aspects is presented on Table 3.
Table 3. The Recapitulation of Technology Engineering Literacy

| No | Aspect                                  | N | Pretest | Posttest | n-gain <g> | SD  | ES  |
|----|-----------------------------------------|---|---------|----------|------------|-----|-----|
| 1  | Understanding technological principle   | 3 | 45.78   | 74.13    | 0.52       | 28.10 | 1.01 |
| 2  | Developing solution and achieving goals | 1 | 50.00   | 87.50    | 0.75       | 46.72 | 0.80 |

Table Technology Engineering Literacy

Technology Engineering Literacy 46.88 76.56 0.56 23.97 1.24

Table 3 shows that there is satisfactory enhancement of technology engineering literacy after students are using STEM based module in their learning practices. First aspect is understanding technological principle which has the result of n-gain score 0.52 with 45.78 of pretest score and 74.13 of posttest score. It means that student’s technology engineering literacy is moderately enhancing on this aspect. This result has effect size score of 1.01 which means that n-gain score has strong effect to student’s knowledge enhancement.

Secondly, developing solution and achieving goals aspect shows the score of 50.00 and 87.50 on pretest and posttest score respectively. Whereas, the calculation of normalized gain score is 0.75 which means that there is strong difference of student’s technology engineering literacy on this aspect and the result of effect size is 0.80 means that it has moderate effect. Overall, student’s technology engineering moderately enhanced (<0.56>) with strong effect size of 1.24.

Student’s technology engineering improved better on developing solution and achieving goals aspect because this aspect is only delivered in one question, thus it will have better chance to gain better normalized gain score because there will be less false answers. In the process of implementation of STEM based module, students do science activity in constructing earthquake proof building. This activity will surely enhance students’ technology engineering literacy because students should do engineering design process to solve problems by implementing technology principle and develop solutions [20]. [19] who revealed that engineering design process enhances student’s creativity, thinking skill and problem solving skill.

3.3. Student’s Mathematics Literacy

There are four questions of mathematics literacy which are delivered in the question number 6, 7, 8, 14 and 20. This measures student’s mathematical processes by answering questions to formulate situations mathematically. The recapitulation of the enhancement of mathematics literacy is presented on Table 4.

Table 4. The Recapitulation of Mathematics Literacy

| No | Aspect                                | N | Pretest | Posttest | n-gain <g> | SD   | ES  |
|----|---------------------------------------|---|---------|----------|------------|------|-----|
| 1  | Formulating situations mathematically | 5 | 30.63   | 52.50    | 0.32       | 19.29 | 1.13 |

Table 4 shows the result of mathematics literacy with 30.63 and 52.50 of pretest and posttest result respectively. The calculation of normalized gain score is 0.32 and effect size score is 1.13 which means that student’s knowledge is moderately enhanced which is strongly affected by the use of STEM based module. After the implementation of STEM based module through science activity in constructing earthquake proof building, student’s mathematics literacy moderately improved because in designing the building, students should implement mathematics calculation into real life.

Although student’s mathematics literacy improved, but the score is still below standard minimum criteria (KKM) of Indonesian government. According to student’s answer sheet, it can be seen that students found difficulties in interpreting problem into mathematical calculation. It is because student’s mathematical skill on doing calculation of multiplication, addition, subtraction and division is low. Students are also difficult to construct and understand information from data presented on graphic, table or figure. Therefore, they could not make summary based on mathematical procedures.
According to [21] students who are able to analyze, do mathematics calculation, communicate mathematical knowledge and skill, solve and interpret mathematical problems are having good level of mathematics literacy. [22] stated that mathematics literacy is someone’s skill to use mathematical understanding to solve real life problem.

3.4. Student’s Science, Technology, Engineering, and Mathematics (STEM) Literacy

Table 5. The Recapitulation of STEM Literacy

| Aspect                  | N  | Pretest | Posttest | n-gain <g> | SD  | ES  |
|-------------------------|----|---------|----------|------------|-----|-----|
| Science Literacy        | 11 | 35.55   | 58.30    | 0.35       | 20.65| 1.10|
| Technology Engineering  | 4  | 46.88   | 76.56    | 0.56       | 23.97| 1.24|
| Literacy                |    |         |          |            |     |     |
| Mathematics Literacy    | 5  | 30.63   | 52.50    | 0.32       | 19.29| 1.13|
| STEM Literacy           | 20 | 34.84   | 57.81    | 0.35       | 17.42| 1.32|

Table 5 shows that student’s STEM literacy moderately enhanced with 0.35 of normalized gain. The effect size of STEM literacy is 1.32 means that moderate enhancement of student’s knowledge is affected by the use of STEM based module in learning practices.

According to the result of STEM literacy in knowledge aspect, students score enhanced on the post-test. However, student’s average score in the post-test is 57.81 and below standard minimum criteria (KKM) of Indonesian government which is 65.00. There might be several reasons towards this. First, students who are involved in this research have never been exposed to STEM based learning. Especially it is in science activity when constructing earthquake proof building, students seem afraid to make mistakes so they asked several questions some of the students even do nothing and should be helped by teacher as a facilitator. In facing new learning style, students need time to adapt themselves following teaching and learning practices. [23] stated that lack of experience, abilities, fear of failure and lack of self-confidence often lead to academic failure.

Another reason is the location of the school where this research is conducted which is in Bubut Montain Street in Soreang, West Java. The location of the school is located in rural area which has different facilities compared to the city. This condition can impact to student’s achievement as [24] stated that civic amenities such as electricity, technology, textbooks, stationary and other materials are essential to enhance student’s learning achievement. However, it comes back to student’s determination, they still will be able to acquire understanding of concepts even when studying in just candle lights if their determination to study is strong. Previous literatures revealed that rural schools have more trouble in helping struggling students [25] and student’s from undeveloped area considerably less weight on academic achievement [26-28].

Moreover, school facility might be another reason to low result of student’s achievement. For instance, in the implementation of STEM based module, teacher found difficulties in using technological devices such as projector and speaker as it is not provided in the classroom and should ask for permission to use it. Additionally, the amount of technological devices are also limited, so not every teacher can use it in their learning practices. This condition can effect student’s performance as stated by [24][29] that learning resources are vital to enhance student’s academic performance because when students are provided with necessary learning tools and equipment, they will acquire better understanding regarding academic concept.

Furthermore, the location of 7-I classroom where this research occurred is located next to a canteen and toilet. This condition interrupts student’s attention especially near school break time. Student’s focus is changing, not to what is happening in the classroom, but to the other students who are buying foods in the canteen. Classroom environment influences student’s focus and their academic performance [24].
The recapitulation of each aspect of STEM literacy is shown on Figure 1.

![Recapitulation of Normalized Gain of STEM Literacy](image)

**Figure 1. The Recapitulation of Normalized Gain of STEM Literacy**

Description:
- **SL**: Science literacy
- **TEL**: Technology engineering literacy
- **ML**: Mathematics literacy

According to figure 1, the highest normalized gain occurred in question number 10 which is in technology engineering literacy on developing solution and achieving goals that shows n-gain score of 0.75 means that there is strong difference of student’s knowledge understanding after they use STEM based module in their learning experience. Meanwhile the lowest difference of student’s knowledge enhancement occurred in question numbers 1, 2, 3, 4, 5, 6, 7, 8, 14 and 20 which are the questions of science literacy on second aspect of interpret data and evidence scientifically aspect as well as the questions of mathematics literacy. These 10 numbers has satisfactory enhancement at 0.32 of n-gain score which means that after using STEM based module student’s knowledge understanding moderately enhanced.

Figure 1 shows that the highest enhancement of student’s conceptual understanding is on technology engineering literacy. STEM is a good approach to enhance student’s technology engineering literacy [30]. However, the lowest enhancement occurred on mathematics literacy. Students find difficulties in interpreting problems into mathematical calculations, this can be seen from their answer sheet. Student’s interest in mathematics is low because they feel it is hard to learn mathematics which contributes to their performance [31].

In general, student’s understanding in science, technology-engineering, and mathematics literacy enhanced after the implementation of STEM based module in learning process. Previous literature indicated that the implementation of integrated STEM instructional modules improved student’s achievement in learning science which has been developed using several approaches and contexts [32-37].

Moreover, student’s STEM literacy on knowledge aspect improved as students do not just learn science topic, but the integration of STEM concepts followed by engineering design process activity which provided opportunity for students to implement their knowledge in solving real world problems. This is in line with [3,38-39] that STEM based learning can construct and develop student’s knowledge in solving real world problems. STEM literacy in knowledge aspect occurred when
students are able to translate, conceptualize, and apply conceptual knowledge in their real world [2] and those who are STEM-literate have real experience towards STEM learning [22]. As STEM literacy is a skill to identify problems which integrates STEM aspects to innovate in solving problems [3].

4. Conclusion
According to the result, student’s STEM literacy enhanced moderately through the use of STEM based module in learning process. The implementation of STEM based module on earth’s structure and its dynamics topic is capable to improve student’s STEM literacy on knowledge aspect. It can be proven by student’s normalized gain <g> score which is 0.35 categorized as moderate enhancement and index effect size of 1.32 in strong category (large effect). The highest enhancement occurred in technology engineering literacy (<g> = 0.56) since the students experienced engineering design process in constructing earthquake proof building, while the lowest enhancement is on mathematics literacy (<g> = 0.32). Overall, the implementation of STEM based module gives strong influence towards student’s knowledge enhancement.

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