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Outline, Validity, Readability, and Response toward the Layout, Content, and Utility Aspects of a STEM-based Module

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Abstract

In the 21st century of technology and digital era, science, technology, engineering, and mathematics (STEM) in education, politics, and economics is becoming an integral part. Implementing STEM in the learning should be followed by the readiness of teachers and supported by STEM-based teaching materials. This study implemented the Design and Development Research (DDR) via six stages to produce a STEM-based module for 7th grade students, particularly on the topic of Earth's Structure and Its Dynamic. The developed STEM-based module followed the basic national competence for secondary level, module criteria, criteria of STEM learning materials, STEM literacy practices, and Engineering Design Processes from NGSS and NRC (2010), OECD (2016), NAEP (2014), and 2013 Revised National Curriculum. Questionnaires were given to experts, teachers, and students to test the validity and readability of the STEM-based module. Moreover, the module was implemented as a learning module in one class of 7th grade students at 03 Public Junior High School, Soreang, which consisted of 32 students. The results showed that the STEM-based module was valid to be used by junior high school students. Moreover, the readability score obtained was 88.39%, while the response towards layout, content, and utility aspects was 94.44%. This means that the module had undergone a minor revision.

INTRODUCTION

In this modern era, science and technology are developing rapidly. As in this century of the technology and digital era, the integration of science, technology, engineering, and mathematics (STEM) is becoming a significant issue, especially in a political, economical, and educational contexts (Faloon et al., 2020; Freeman, Marginson, & Tytler, 2019). STEM education should implement the interdisciplinary approach where academic and real-life contexts are integrated by applying it (Permanasari, Rubini & Nugroho, 2021).

STEM literacy is the integration of knowledge, skill, and attitude, which is STEM-driven and necessary to be possessed by a working-age adult (Jackson et al., 2015). STEM literacy has become a worldwide issue that connects the cognitive, affective, and psychomotor domains to solve a real-world problem by integrating STEM concepts and skills using integrated scientific discipline (Falloon et al., 2020; Utami, Rochintaniawati & Suwarma, 2020; Breiner et al., 2012; Zollman, 2012).

STEM literacy has four aspects. First, Science, Technology, Engineering, and Mathematics concepts are delivered as an integral material (Sanders, 2012). Second, the integration of content and pedagogy aspects engages students' activities to put focus on conducting an investigation, experiment, and research to solve a real-world problem. Third, STEM literacy focuses on students' attitudes, beliefs, self-esteem, confidence, skills, and behaviour (National Research Council, 2011). Fourth, STEM-based education involves activity in operating technology while studying and solving the problem (Zollman, 2012).

The idea of developing suitable STEM-based instructional material arises from the result of Trends in International Mathematics and Science Study (TIMSS), which reveals that, on average, the 4th grade of Indonesian students is ranked 44th among 49 participants (Hadi & Novaliyosi, 2019). This result should be noticed and marked as essential to enhance educational quality in Indonesia.

According to Khalil and Osman (2017), STEM education nurtures the 4Cs of 21st-century learning: critical thinking, communication, collaboration, and creativity. The STEM-based instructional material contains assessment sheets and engineering-based project. On the other hand, the content written inside the module facilitates students to integrate STEM in developing students understanding and problem-solving skills.

Moore et al. (2014) and Walker et al. (2018) agreed that content delivered in STEM-based instructional material should contain engineering design problems to explore broad learning content. Andrews et al. (2014) stated that the STEM-based module provides not only STEM concepts, but it also contains a series of projects, activities, assessments, and evaluations. In this study, the STEM-based module meets the eight criteria of science and engineering practices outlined by NRC (Bybee, 2011).

Nulhakim and Setiawan (2021) stated that although STEM education has been widely implemented in the school system in Indonesia, it should also be followed by the readiness of STEM-based education (teaching capability and instructional materials). For instance, a STEM-based worksheet was constructed by Gustiani, Widodo, and Suwarma (2017) to measure students' engineering design behaviour. Providing STEM-based education in the classroom is challenging since it needs equal representation of the four STEM disciplines (King and English, 2016). Usually, only one STEM discipline dominates the whole activity, which is not a STEM approach (Honey et al., 2004).

Therefore, this study presents the development of a STEM-based module that meets the criteria of STEM education and engineering design process according to Bybee (2011), English and King (2015), and Jolly (2015), particularly on the topic of Earth Structure and Its Development for 7th grade students.

RESEARCH METHOD

This study implemented the Design and Development Research (DDR) to produce a STEM-based module for 7th grade students, particularly on the topic of Earth's Structure and Its Dynamic. In developing a STEM-based module, six stages were executed, starting from identifying the problem, describing the goals and purposes, designing and developing stage, testing the product, evaluating and revising, and finally communicating the test results.

Figure 1. DDR Flow (Peffers et al., 2007)

The DDR method, which was implemented to produce STEM-based modules, consisted of i) conducting a systematic study of design and development based on need-analysis, and ii) testing the validity, effectiveness, and reliability to establish an empirical basis of learning materials (Richey and Klien, 2007).

The construction of a STEM-based module follows the basic national competence of secondary level, module criteria, STEM literacy practices, Engineering Design Process from NGSS and NRC (2010), OECD (2016), NAEP (2014), and 2013 Revised National Curriculum. To test its validity and readability, the STEM-based module is assessed by experts, lecturers, and teachers and implemented as a learning module in one class of 7th grade students at 03 Public Junior High School, Soreang, which consisted of 32 students.

The validity of the STEM-based module consisted of content, layout, and lexical aspects via validation sheets. On the other hand, the readability of the module consisted of clarity of text, pictures, and ideas presented inside the module. Moreover, the difficulty level of the quizzes and questions was also assessed. The formula for calculating the readability score according to Mardapi (2011) is given as follows:

$$\text{readability} = \frac{\text{raw score}}{\text{maximum score}} \text{ x } 100. \qquad (1)$$

Moreover, to obtain the response of the users towards STEM-based module, teachers (above ten years of teaching experience) and high school students (higher achiever students; rank 1-3) were asked to read, use, and fill the questionnaire concering layout, content, and utility aspects.

RESULTS AND DISCUSSION

Structure of the STEM-based Module

In this study, a STEM-based module is constructed for 7th grade students of Junior High School, printed in A5 paper size. Moreover, the module discusses the topic of Earth's Structure and Its Dynamic. The module has 32 pages in total; one cover page, 20 pages of the main topic, and 11 pages of an Engineering Design Process-based project.

The STEM-based module outline is created based on the National Research Council's (NRC) 8 steps of science and engineering practices (Bybee, 2011); engineering design process (NGSS); a summary of literature review about STEM content, STEM literacy aspects, and engineering design process activity. The construction of the STEM-based module outline is given in Table 1.

Table 1. The outline of the STEM-based module.

Outline		Item Description	Page
Eight steps of science and engineering practices (Bybee, 2011)	Asking questions and defining problems	On the first page of the module, a question assessing students' prior knowledge about the Earth's layers is presented.	1
	Developing and using a model	A picture of an onion illustrates the layers of Earth.	2
	Planning and conducting an investigation	Students are asked to investigate the convection process of boiling water, which has relation to the mechanism of the Earth's movement.	5
	Analyzing the data and interpretating	After investigating the convection process, students are asked to analyze the heat transfer mechanism inside the Earth's layers.	5
	Developing mathematical and computational thinking	When an earthquake occurs, the earthquake's magnitude can be measured and calculated.	8-12
	Constructing explanations and designing solutions	The earthquake's magnitude, energy, epicentrum position, and distance can define the earthquake's effect. Students are asked to explain the data and design possible solutions to the earthquake.	12
	Engaging in argument from evidence	The article from BBC about the volcanic eruption in Merapi mountain is presented. Students are then asked to identify the process of a volcanic eruption from what they have read.	15
	Obtaining, evaluating, and communicating information	Students' ability to obtain, evaluate, and communicate information is obtained through quizzes on volcanic eruptions and the water cycle.	17 – 20
Excellence criteria of STEM learning materials (Jolly, 2014)	Focus on real-world issues and problems	As Indonesia is located in the ring of fire, earthquakes, volcanic eruptions, and tsunamis are becoming the current issues.	21
	Guided by the engineering design process	The second part of the module follows the engineering design process, a project to construct an earthquake-proof building.	21-23
	Immerse in hands-on inquiry and open-ended exploration	The project is constructed via hands-on and collaboration experience, where students can control, design, and investigate to answer questions.	22-25
	Involve productive teamwork	The engineering-based project initiates students to work in a team.	22-25
	Apply rigorous science and mathematics content	The STEM-based module consisted of science, science-technology, science-technology-mathematics, technology-engineering, technology-mathematics, and science-technology-engineering sections.	1-30
	Allow for multiple correct answers	In the engineering-based project, students answer the questions based on what they found and experienced.	28-30
STEM Content	Science	Lithosphere, hydrosphere, Earth's structure, seafloor spreading, earthquake, volcanic eruption, seafloor spreading, volcanic eruption material, continental drift theory, disaster risk reduction, volcanic formation process, hydrology.	1-4, 6, 14-20
	Science Engineering	The convection process occurred on earth.	5
	Science Mathematics	The magnitude of earthquakes and tsunamis.	7, 11-13
	Science Technology	Earthquake magnitude and its calculation on the	8

Outline		Item Description	Page
	Mathematics	seismograph.	
	Technology Engineering	Seismograph interpretation.	9
	Technology Engineering Mathematics	The calculation of earthquake magnitude and its scale interpretation.	10
Engineering Design Process (EDP) from English and King (2015)	Define problems	The problem of constructing an earthquake-proof buildings is presented with limited tools and time.	21-22
	Conduct background research	As architect engineers, students must solve the problem by constructing earthquake-proof buildings.	22-23
	Develop solutions	Six questions must be answered before constructing the building to define the solution.	24-25
	Create prototype	Before constructing an earthquake-proof building, students have to make a prototype (design and plan) and conduct a mathematical analysis of the building.	26-27
	Test	The stability and strength of the building are tested by adding loads and placing them on a shaking table.	28
	Evaluate	Students should answer seven questions about the performance, strength, and stability of their building.	29
	Redesign	After the testing and evaluation stages, students have a second chance to redesign, repair or reconstruct the building.	30
	Formulating conclusion	In the final stage, students are asked to make a conclusion, answer the final question, and submit their final building.	31

The first part of the STEM-based module on pages 1 to 20 is based on eight steps of science and engineering practices (Bybee, 2011). As shown in Table 1, the first part focuses on delivering the topic of Earth's Structure and Its Dynamics, which follows the competencies of the 2013 Revised National Curriculum 2013. Developing a STEM-based module should be systematically compact as part of learning materials to achieve learning competency (Darma et al., 2019). Agustina, Rahayu & Yuliani (2021); Irwandani & Juariyah (2016); Rodriguez (2015) agreed that linking materials and concepts of real-life problems and bringing them into learning practices would ease students in understanding and meaningful knowledge.

This study divides the STEM-based module into six sections based on the contents, i.e.: science-engineering, science, science-technology-mathematics, science-mathematics, technology-engineering-mathematics, and technology-engineering. Some of them can be seen in Figures 2 and 3.

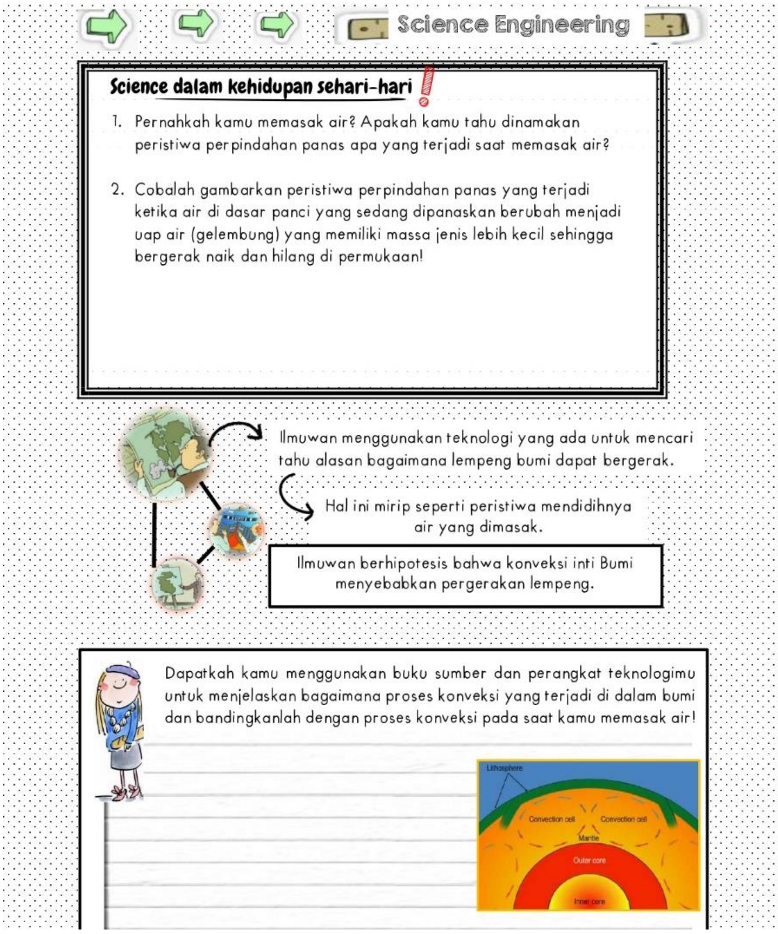

Figure 2. Science-Engineering

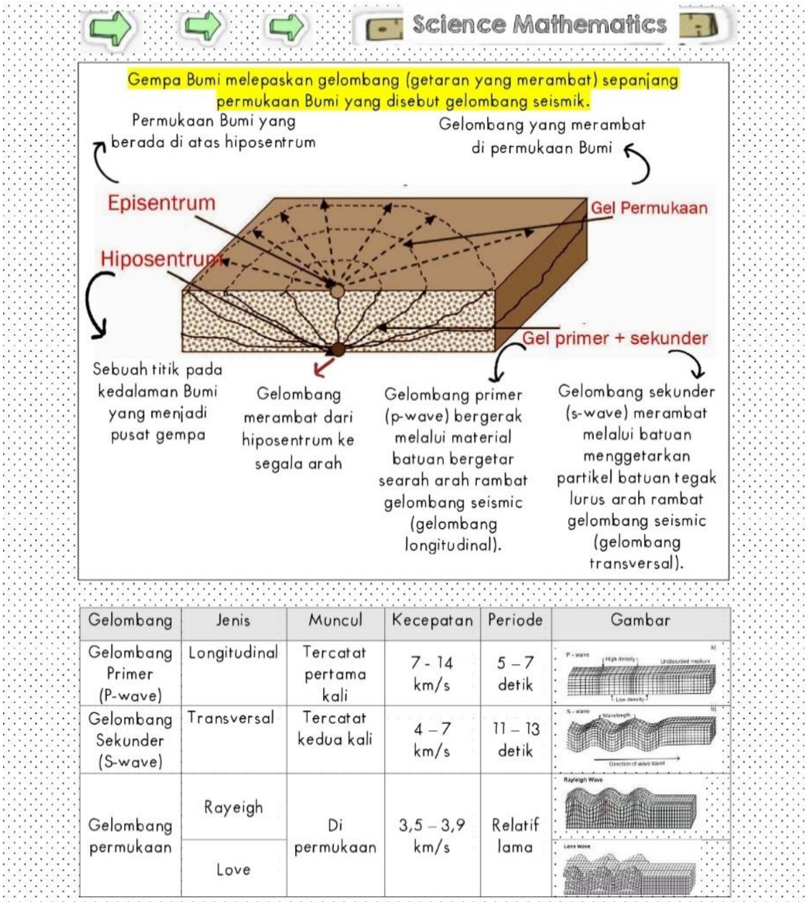

Figure 3. Science-Mathematics

According to Holbrook & Rannikmae (2009) and Lopez et al. (2011), relevancy in daily life is an essential part of the learning module as it guides students to construct concrete understanding and experience when learning STEM subjects. The content delivered in this module closely relates to daily life problems to make students easier in understanding one particular topic in real life. For instance, page 5 of the module talks about the Earth's convection process, which is causing earthquakes and volcanic eruptions. Students might find it hard to understand how the Earth's plate can move. However, in this module, students identify a real-life convection process of boiling water to represent how the earth's convection process occurs and the result of heat transfer. Thus, Earth's plate can move (earthquakes and volcanic eruptions). Examples and illustrations presented in the module enhance students' understanding (Chiu & Linn, 2014). Wolfenbarger & Sipe (2007) agreed that illustration of a phenomenon would sharpen students' understanding, stimulate imagination, and enhance research skills.

Using the STEM-based module enhances students' STEM interest as the conducted engineering design-based project relates to students' fundamental problems (Toma & Greca, 2017). Engineering Design Process is an essential phase when implementing STEM education as it helps students develop broader ideas, enhance their ability, and retain better understanding (Andrews et al., 2014).

English & King (2015) stated that STEM-based education puts focus on the Engineering Design Process, which leads students to solve real-world problems with creative and innovative solutions, and integrate STEM concepts. Inside the STEM-based module is a student's STEM-based project on creating an earthquake-proof building. The STEM-based project is constructed according to Engineering Design Process by English & King (2015) known as *pikir* (think), *desain* (design), *buat* (create), *uji* (evaluate) or PDBU on pages 21 to 31 where the samples can be seen in Figure 4.

Figure 4. Engineering Design Project Worksheet

Validation Results

Table 2. Validation results on the content aspect.

Validation Criteria	% Score			Category
	*V-1	*V-2	*V-3	
In accordance with basic competence	√	√	√	Satisfying
Integrate STEM concept	√	√	√	Satisfying
Understandable content	√	√	√	Satisfying
Content is written in a good structure	√	√	√	Satisfying
Develop student's engineering process design	√	√	√	Satisfying
Questions delivered can initiate student's engineering process design	√	√	√	Satisfying

*V stands for Validator.

Table 2 presents the validation results of the STEM-based module on the content aspect. According to the validation results, the STEM-based module is able to facilitate the instructional module's needs, which integrates the STEM concept. In constructing the module, the two main sections, i.e.: the STEM part and the engineering design process are the keys to producing a valid STEM-based module. The engineering design challenge, which offers an opportunity to integrate the STEM concept, could provide valid and reliable instructional modules (Mathis et al., 2018; Moore et al., 2014). According to Andrews et al. (2014), a STEM-based module delivers STEM content. It provides a series of activities as supplemental learning material measuring students' understanding and ability, including assessment and evaluations.

Table 3. Validation results on layout aspect.

Validation Criteria	% Score			Category
	*V-1	*V-2	*V-3	
Has interesting design	√	√	√	Satisfying
Pictures are appropriate for the topic	√	√	√	Satisfying
Text is clear (appropriate text size and font)	√	√	√	Satisfying
Good combination of text and pictures	√	√	√	Satisfying
Clear content layout	√	√	√	Satisfying
Has enough space for student's response	√	√	√	Satisfying

*V is stands for Validator

According to the validation results in Table 3, there is a minor revision in the layout of the STEM-based module. However, it is concluded that the design, text style, pictures, and layout of the STEM-based module are appropriate. In constructing a STEM-based module, Wolfenbarger & Sipe (2017) stated that pictures, design, and written text could enhance students' understanding, stimulate creativity and imagination, sharpen perception and thinking skills, and raise a sense of observation. Inside the module, there is enough space for students to make notes, answer questions, or make a highlight. The font style used is *Futura Handwritten* which gives the sense of pen writing but is still clear and readable. Moreover, the pictures presented inside the module are illustrations with attractive colours. In constructing the STEM-based module, the layout aspect is also becoming important as Kilickaya (2015) and Solcova & Magdin (2016) found that it would facilitate students to learn more.

Table 4. Validation results on lexical aspect.

Validation Criteria	% Score			Category
	*V-1	*V-2	*V-3	
Use standard Indonesian language	√	√	√	Satisfying
Use communicative and interactive language	√	√	√	Satisfying
The language used is appropriate for students’ development	√	√	√	Satisfying
Has good sentence structure	√	√	√	Satisfying
Use appropriate terms	√	√	√	Satisfying
Words and terms used are consistency	√	√	√	Satisfying
Text written is easily understandable	√	√	√	Satisfying

*V stands for Validator

The validation results in Table 4 show that the STEM-based module has an appropriate lexical structure. The lexical structure is becoming an important aspect in constructing instructional material as it has a great impact on students’ understanding and academic performance (Arya, Hiebert & Pearson, 2017). It is also obtained that the STEM-based module is written in understandable, clear, concise, and consistent words, terms, and sentence according to the standard Indonesian language.

Readability Results

A questionnaire is used to measure the readability of the STEM-based module, which consists of text comprehension, formulating main ideas, and quiz comprehension. The questionnaires are given to 30 high school students. The results may be observed in Figure 5.

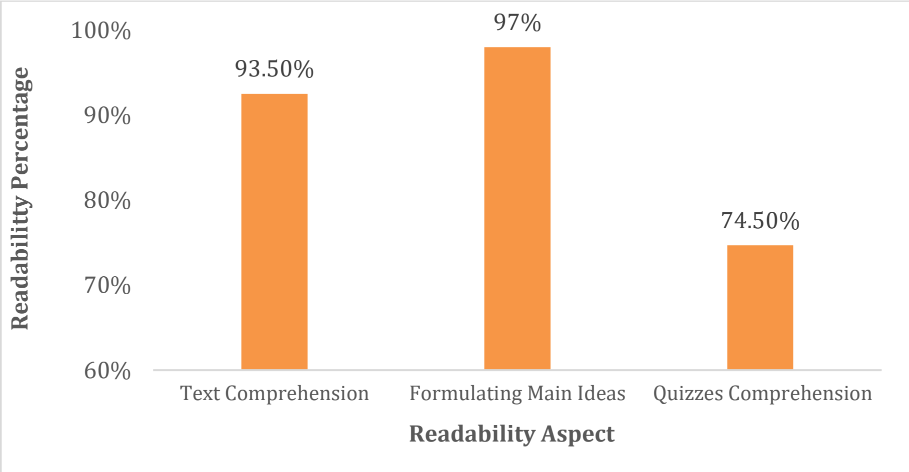

Figure 5. Readability results of the STEM-based module.

Text comprehension and formulating main ideas are the two aspects that obtained a high percentage above 90% while the quizzes comprehension is just below 75%. Notably, 93.50% of users agreed that they understood the text after the reading session. However, based on the results, 7.5% believe that scientific words such as divergent, convergent, epicentrum, and fault are unfamiliar.

The text formulating result shows the highest percentage of 97%, indicating that most users understand the text inside the module. Hence, they can construct the main idea perfectly. In determining the main ideas, recalling important information improves students' ability to understand the written text (Denton et al., 2007).

Slightly below three-quarters of the respondents can comprehend the quiz, while the rest find it hard to answer and understand the question. This reflects their existing knowledge (Nagy & Hiebert, 2011). To sum up, the average score of STEM-based module readability is 88.33%, which means that minor revisions need to be done.

The Response to STEM-based Module

A questionnaire consisting of 25 positive statements is provided to teachers with more than ten years of teaching experience and highest achiever high school students (rank 1 - 3 in class) to enhance the quality of the STEM-based module.

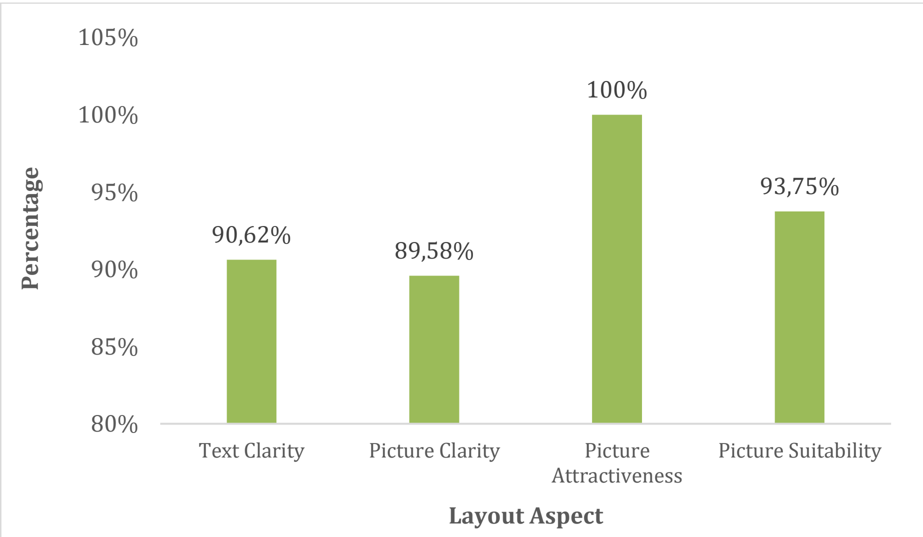

Figure 6. The response toward layout aspect.

According to the result in Figure 6, picture clarity receives the lowest percentage of below 90%, as the pictures presented in the STEM-based module are not the actual pictures but rather the illustrations. Thus, the pictures in the module might not be as clear as the actual pictures. Other reasons can be the printing technique as well as paper and ink quality, which influence the clarity of the pictures (Sari & Suryana, 2019). However, picture attractiveness shows 100%, which means that the entire respondents strongly agree that the pictures printed on STEM-based modules are attractive.

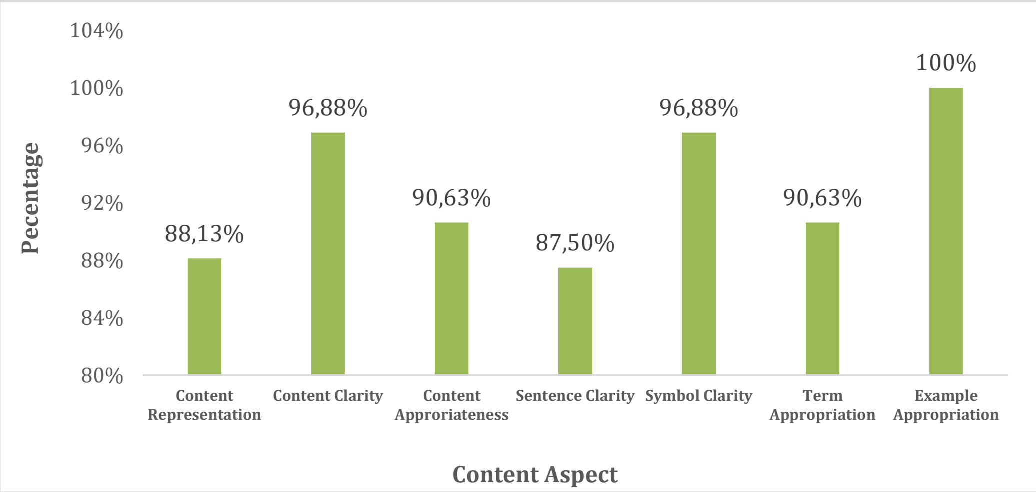

Figure 7. The response toward content aspect.

Figure 7 presents the response towards STEM-based modules on the content aspect. The STEM-based module could appropriately explain science concepts, particularly on thej topic of Earth's Structure and Its Dynamics. The appropriateness of content representation could encourage an active learning process because it encourages students to bravely pose questions regarding daily life problems and encourage peer interaction (Gustiani, Widodo & Suwarma, 2017). Moreover, sentence clarity reaches the lowest score of 87.50% but is still categorized as having clear and understandable language. As seen in the module, the sentence is mostly written in simple form with no ambiguous sentences, making it easier for readers to understand and follow illustrations and examples. However, in developing a STEM-based module, integrating STEM concepts is challenging. Interpreting mathematical calculations into sentences is one factor that makes sentence becomes unclear. Jupri & Drijvers (2016) stated that mathematizing words and interpreting mathematical models are two main difficulties faced by students when learning STEM concepts.

On the other hand, the example appropriateness aspect reaches 100%, which means that the examples presented in the module are based on real-life problems to enhance student's understanding of learning science. Chiu & Linn (2014) stated that simulation, animation, and all kinds of examples could improve students' understanding and help them develop simple explanations of complex materials. Moreover, Rodriguez (2015); Irwandani & Juariyah (2016) agreed that linking materials and concepts of real-life problems and bringing them into learning practices would ease students' understanding and increase knowledge. In a study conducted by Nas & Calik (2018), students were confused about the concept of soil erosion. They found that developing analogies and computer simulations can overcome this confusion.

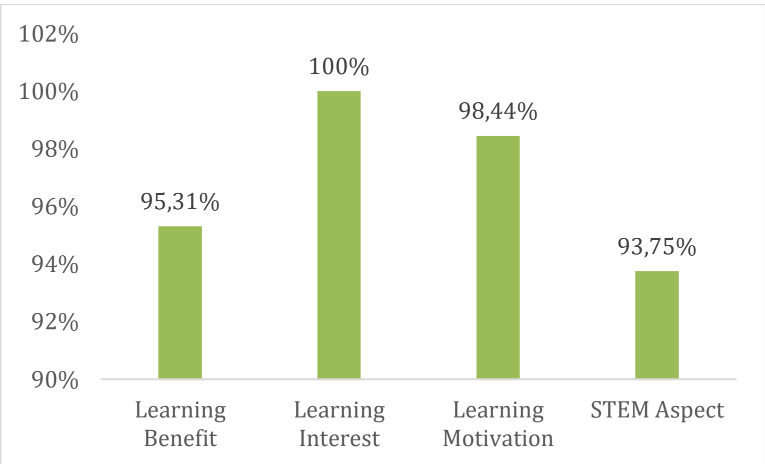

Figure 8. The response towards the utility aspect.

Interest and motivation are the two expressive power that energizes students to study and enhance understanding, which are essential to achieve academic success (Gillet et al., 2012; Judith, Jessi & Stacy, 2016). Interestingly, Figure 8 shows learning interest results reach 100%. This indicates that STEM-based modules can attract students' interest and motivation to learn science. Moreover, the result of learning motivation shows 98.44%. This means that the STEM-based module motivates readers to study more about the topic.

All in all, the average score of students' and teachers' responses to STEM-based instructional modules is 94.44%. This means that this module provides appropriate layout, content, and utility that can be used as a learning material in delivering science concepts through STEM learning.

CONCLUSION

The STEM-based module developed in this paper meets the criteria of STEM education and the engineering design process. According to the results, the developed STEM-based module is also valid to be used by 7th grade students of junior high school, particularly in learning thej topic of Earth's Structure and Its Dynamics topic. Moreover, both readability and response toward the STEM-based module on layout, content, and utility aspects show quite high percentages.

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