Multimedia development based on science technology engineering and mathematics in microbiology learning

Trio Ageng Prayitno*, Nuril Hidayati

Biology Education, IKIP Budi Utomo Malang, Jl. Simpang Arjuno No.14B, Malang, (65119), East Java, Indonesia.

*Corresponding author: trioageng@gmail.com

ABSTRACT

Microbiology learning has not used multimedia based on science technology engineering and mathematics (M-STEM) which can help students understand the concept of microbiology and empower 21st-century skills. The purpose of this research was to develop M-STEM in microbiology learning. The research method uses research and development (R&D) with the Borg and Gall development model which consists of seven stages. The research sample was 20 students who had participated in microbiology learning and four microbiology lecturers at the department of biology education, IKIP Budi Utomo. The research instrument used a questionnaire, interview transcripts, expert validation sheets, practitioner validation sheets, and readability test sheets. The research data is the percentage of the validation score from experts, practitioners, and readability tests. The research data analysis was carried out by descriptive qualitative. The results showed that M-STEM was declared strongly valid in the aspect of media (88.36%), material (97%), usefulness in microbiology learning (99.49%), and readability (88.82%). M-STEM contains interesting features, is easy to access and operate, and the information in it is easy to understand. This research concludes that M-STEM can be recommended for use in microbiology learning.

INTRODUCTION

Higher education must have a Tri Dharma paradigm which is in line with the era of the industrial revolution 4.0 by using three literacies, namely digital literacy, technological literacy, human literacy, and focus on lifelong learning (Kemenristekdikti, 2018a). The era of the industrial
revolution encouraged learning to use new literacy to develop students' skills (Ahmad, 2018). Lecturers must have high competence to motivate the development of students' skills (Wahyuni, 2018; Yusnaini & Slamet, 2019). Student skills that must be prepared in the era of the industrial revolution 4.0 are skills that can solve problems in the 21st century such as higher-order thinking skills (Van Rosmalen, Boyle, Van der Baaren, Kärki, & del Blanco Aguado, 2014).

Higher-order thinking skills consist of critical thinking, creativity, collaboration, and communication (Hermana, 2019; Zubaidah, 2018a). Critical thinking skills are skills to use knowledge to find out problems and find solutions to problems appropriately (Koziokoglu, 2019; Widawati, Joyoatmojo, & Sudiyanto, 2018). Creative thinking skills are skills to get new and unique ideas. Collaboration skills are the skills to interact flexibly and effectively with others. Communication skills are the skills to express ideas and solutions in the best way through spoken and written (Zubaidah, 2018a; Fajrina, Lufri, & Abda, 2020). The high-order thinking skills above can be developed with a quality learning process (Widarti, Rokhim, & Syafruddin, 2020). One of the supports for the quality learning process is teaching materials. The recommended form of teaching materials includes the integration of learning materials and learning approach (Hidayat, Sarmi, Fisika, & Padang, 2020).

The results of observations on microbiology learning from the department of biology education, IKIP Budi Utomo show that microbiology learning has not used learning media integrating digital, technology, and human. Microbiology learning has not used learning media that supports the achievement of 21st-century skills. Microbiology learning here is still focused on improving cognitive learning outcomes, as shown in cycle I was 73.04 to cycle II was 79.77 and using digital-based multimedia such as multimedia-Edmodo which has not empowered 21st-century skills (Prayitno & Hidayati, 2017a). Cognitive learning outcomes are important to improve in microbiology learning, but it will be more important to improve 21st-century skills in the era of industrial revolution 4.0 because this era requires the use of 21st-century skills such as critical thinking skills, creative skills, collaboration skills, and communication skills to live in a society (Yusnaini & Slamet, 2019). This problem is important to be resolved immediately so that students have the skills to live in the era of the industrial revolution 4.0.

One solution to the problem is the development of multimedia-based on science technology engineering and mathematics (M-STEM). M-STEM is important to be developed to collaborate between digital, technology, and human. Multimedia can combine text, video, audio, internet technology, and digital devices and make learning more dynamic (Almara'beh, Amer, & Sulieman, 2016). The learning of science technology engineering and mathematics (STEM) is integrated into multimedia because it can empower 21st-century skills. STEM can motivate students to plan, investigate, engineering, interpret data, think critically, innovate, create and collaborate (Bybee, 2011; Kennedy & Odell, 2014; Wang, Charoenmuang, Knobloch, & Tormoehlen, 2020). The development of multimedia-based on STEM can enhance students' 21st-century skills such as critical thinking skills (Hidayati & Irmawati, 2019; Hidayati, Irmawati, & Prayitno, 2019).

This research focuses on the development of M-STEM in microbiology learning with the Borg and Gall development model. Multimedia is developed by containing learning outcomes, material text, images, video, audio, mini-quizzes, mini labs, worksheets based on STEM, tests to empower critical thinking skills and communication skills, and scores that can be seen live. The tests contained in M-STEM are designed to be used to empower critical thinking skills and communication skills. Critical thinking and communication skills are two important skills in microbiology learning to be empowered to enable students to find problems and solutions in the aspects of microbiology and be able to convey problem-solving through oral and written well to others. These two skills can be called 2C, which are basic skills for living in a society in the era of the industrial revolution 4.0. Previous research stated that multimedia only contains text on
microbiology, audio, and does not contain a learning approach (Prayitno & Hidayati, 2017b). Furthermore, the material contained in M-STEM from the previous research is human physiological anatomy (Hidayati & Irmawaii, 2019). The development model used by the two previous researchers was the Four-D Thiagarajan model. Based on the explanation above, the purpose of this research is to develop M-STEM in microbiology learning.

**RESEARCH METHODS**

**Research Design**

This research was a research and development method (R&D) with a development model by Borg and Gall which consists of seven stages. The research was limited to seven stages because of limited time. The seven stages by Borg and Gall include: (1) research and information collecting, (2) planning, (3) develop a preliminary form of product, (4) preliminary field testing, (5) main product revision, (6) main field testing, and (7) operational product revision (Zubaidah, 2018b). The research and development method can be seen in Figure 1.

**Figure 1.** The research and development method design using the Borg and Gall model.

**Population and Samples**

The population in this study were 68 students who had taken microbiology learning and microbiology lecturers as practitioners of the department of biology education at IKIP Budi Utomo. The sample was taken through a random sampling technique that did not require special criteria in sampling because it assumed that all subjects had the same criteria to represent the population. The number of samples used was 20 students and four microbiology lecturers.

**Instruments**

The research instruments used were student questionnaires, interview transcripts for lecturers, M-STEM validation sheets for experts (media and material), M-STEM validation sheets for practitioners, M-STEM readability assessment sheets for students as users. The student questionnaire consisted of 40 questions about student responses to M-STEM and microbiology learning that had been carried out. This student questionnaire was given to 43 students who had participated in microbiology learning to get information about student responses to M-STEM and their experiences in learning microbiology. The interview transcript consists of 25 questions about the learning methods applied, the learning media used, the knowledge and skills measured, and the problems encountered in microbiology learning. Interview transcripts were given to four microbiology lecturers. The M-STEM validation sheet for media experts contains questions about the requirements for good learning media including visualization, design, layout, and illustrations. The M-STEM validation sheet for material experts contains questions about the correctness of the concept of microbiological material. The M-STEM validation sheet for practitioners contains a statement about the suitability of M-STEM as a learning media in microbiology learning. The M-STEM validation sheet for users contains questions about the clarity of the content, the correctness of the material, the interest of the lecturers, and the importance of the application in daily life.
STEM readability assessment sheet for students contains questions about student responses to M-STEM as users in microbiology learning. This instrument was adapted from previous research by Prayitno & Hidayati (2017) and Hidayati & Irmawati (2019).

**Procedures**

The research procedure consisted of the seven stages from Borg & Gall. These seven stages include: (1) The first stage is research and information collecting, researching student and lecturer responses to M-STEM in microbiology learning through a survey method with a sample of 43 students and 4 microbiology lecturers at the department of biology education, IKIP Budi Utomo, and conducting comprehensive studies on relevant research journals with multimedia in microbiology learning and multimedia based on M-STEM; (2) The second stage is planning, implementing planning to compile M-STEM in microbiology learning which includes the menu features of M-STEM and easy access to M-STEM by users. Next, planning the microbiology material in M-STEM is based on the findings in the first stage. Microbiological material that is planned in M-STEM such as the history of microbiology, comparison of prokaryotic and eukaryotic cells, characteristics and classification of microorganisms, and microbial metabolism; (3) The third stage is developing a preliminary form of product, designing M-STEM with a focus on the completeness of the attractive M-STEM menu features and easy access by users. M-STEM is made using adobe flash software so that it can be easily accessed via the user's computer, laptop, and smartphone; (4) The fourth stage is preliminary field testing, carrying out the M-STEM validation test for material experts, media experts, and practitioners to determine the feasibility of M-STEM in microbiology learning; (5) The fifth stage is the main product revision, fixing the shortcomings of M-STEM based on suggestions from experts and practitioners to produce the perfect M-STEM as a learning media; (6) The sixth stage is the main field testing, carrying out the M-STEM readability test for students as users to find out the readability of M-STEM; (7) The seventh stage is operational product revision, correcting the deficiencies of M-STEM based on suggestions from students as users to produce the perfect M-STEM based on the needs of students.

**Data Analysis**

The research data is the score of the validation results of experts, practitioners, and the readability test by the user which is analyzed descriptive qualitative. The research data is calculated using Formula 1. Furthermore, the data calculated results adjusted to the validation criteria that can be seen in Table I (Hidayati, Pangestuti, & Prayitno, 2019).

\[
\text{Percentage} = \frac{\text{number of answer from respondents}}{\text{number of the ideal answer in one item}} \times 100\% \tag{Formula 1}
\]

| Validity Value (%) | Validity Criteria     | Description |
|--------------------|------------------------|-------------|
| 81-100             | Strongly valid         | Not revise  |
| 61-80              | Valid                  | Not revise  |
| 41-60              | Fairly valid           | Revise      |
| 21-40              | Less valid             | Revise      |
| 0-20               | Strongly not valid     | Revise      |

**RESULTS**

Research and information collecting, at this stage researching student and lecturer responses to multimedia based on STEM (M-STEM) in microbiology learning. The research was conducted...
using a survey method with a sample of 43 students and four lecturers of the department of biology to determine the responses of students and lecturers to M-STEM in microbiology learning. The results of this research indicate that students strongly agree with multimedia (62.80%), students are very interested in multimedia (25.60%), students rarely study with STEM education (60.50%), students agree to use STEM education in microbiology learning (58.10%), students interested in M-STEM (90.7%), students agree with M-STEM because it can help to understand the concept of microbiology (58.10%), all lecturers agree to use STEM education in microbiology learning (100%), all lecturers say students are ready to use multimedia (100%), and all lecturers strongly agree to use M-STEM in microbiology learning (100%).

Planning, based on the results of research and information collecting above, planning is needed to compile M-STEM in microbiology learning. STEM-based multimedia (M-STEM) must be easily accessed by students anywhere using a laptop or mobile phone so that it is designed using the Adobe Flash Player application. M-STEM must contain a complex menu such as learning outcomes, microbiology material text, images, videos, audio, worksheets based on STEM, mini labs, mini-quizzes, ebooks, critical thinking skills tests, communication skills tests, and live scores. M-STEM must contain the text of fundamental microbiology material which is useful for strengthening the scientific foundations of students' microbiology such as the history of microbiology, comparison of prokaryotic and eukaryotic cells, characteristics, and classification of microorganisms, and microbial metabolism.

Developing a preliminary form of product, at this stage, the M-STEM design was carried out using the Adobe Flash Player application and published in the SWF format so that it was easily accessed by students using laptops or mobile phones and using Indonesian. The M-STEM feature in each microbiology material consists of an overview menu, material text, STEM education-based worksheets, mini labs, mini-quizzes, ebooks, tests of critical thinking skills, and communication skills in the form of self-assessment, and test scores that can be viewed live. Besides, M-STEM also integrates text, images, video, audio, google link form, navigation buttons, appreciation, and animation that features the M-STEM is very attractive to users. The features of M-STEM in microbiology learning can be seen in Figure 2, Figure 3, and Figure 4.

Figure 2. Material features of the history of microbiology on M-STEM

Figure 3. The material of microbiological history on M-STEM
Preliminary field testing, M-STEM was tested on media experts (Mr. Eko Fachturn Rochman, M.Kom.-IT developer), material experts (Mrs. Purwaning Budi Lestari, lecturer of microbiology), and practitioners (Mrs. Ismi Nurul Qomariyah, lecturer of microbiology) to determine the validity of the M-STEM that has been developed. The results of the media expert validation can be seen in Table 2. The results of the material expert validation can be seen in Table 3. The results of practitioner validation can be seen in Table 4.

Table 2. The results of the media expert validation on M-STEM

| No. | Item                                           | Validity Value (%) | Criteria      |
|-----|------------------------------------------------|-------------------|---------------|
| 1.  | M-STEM visualization                          | 87.50             | Strongly valid|
| 2.  | M-STEM design                                 | 87.50             | Strongly valid|
| 3.  | M-STEM typography                             | 87.50             | Strongly valid|
| 4.  | M-STEM illustration                           | 75.00             | Valid         |
| 5.  | M-STEM content design                         | 95.83             | Strongly valid|
| 6.  | The typography of M-STEM content              | 87.50             | Strongly valid|
| 7.  | Illustration of M-STEM contents               | 97.67             | Strongly valid|
| 8.  | M-STEM language eligibility                   | 83.33             | Strongly valid|
| 9.  | The completeness of the presentation on the M-STEM | 91.67 | Strongly valid |
|     | The average of validity value                 | 88.36             | Strongly valid|

Table 3. The results of the material expert validation on M-STEM

| No. | Item                                           | Validity Value (%) | Criteria      |
|-----|------------------------------------------------|-------------------|---------------|
|     | Part I. Microbiological material on M-STEM in general |                  |               |
| 1.  | Completeness of the material                   | 93.75             | Strongly valid|
| 2.  | Accuracy of Material                           | 91.67             | Strongly valid|
| 3.  | Presentation of Material                       | 100               | Strongly valid|
|     | Part II. The Truth of the Concept of Matter    |                  |               |
| 1.  | History of microbiology                        | 97.22             | Strongly valid|
| 2.  | Comparison of Prokaryotic and Eukaryotic Cells | 98.44             | Strongly valid|
| 3.  | Characteristics and Classification of Microorganisms | 97.06 | Strongly valid |
| 4.  | Microbial Metabolism                           | 98.75             | Strongly valid|
|     | The average of validity value                  | 97.00             | Strongly valid|
Table 4. Practitioner validation results on M-STEM

| No | Item                                      | Validity Value (%) | Criteria     |
|----|-------------------------------------------|--------------------|--------------|
| 1  | M-STEM design                             | 100                | Strongly valid |
| 2  | Complete M-STEM content                   | 98.21              | Strongly valid |
| 3  | The material on M-STEM                    | 100                | Strongly valid |
| 4  | Types of worksheets on M-STEM             | 100                | Strongly valid |
| 5  | Critical thinking skills test on M-STEM   | 97.73              | Strongly valid |
| 6  | Minilab and mini quiz on M-STEM           | 100                | Strongly valid |
| 7  | Communication skills test on M-STEM       | 100                | Strongly valid |
| 8  | Suitability with the level of student development | 100 | Strongly valid |
|    | The average of validity value             | 99.49              | Strongly valid |

Table 2 shows that the average value of the M-STEM validity from the media aspect is 88.36% (very valid criteria). Table 3 shows that the average value of the M-STEM validity from the material aspect is 97.00% (very valid criteria). Table 4 shows that the average value of the M-STEM validity from the usability aspect of microbiology learning is 99.49% (very valid criteria).

Main product revision, media experts comment that the material on electronic learning is good and this multimedia deserves to be published. Media experts provide advice on the development of further multimedia so that it can be accessed in the android or IOS version, and the design is made more attractive. The revision of the media expert’s suggestion, namely M-STEM has been designed in an SWF format that is easily accessible via mobile phone and the M-STEM feature has been made more attractive by adjusting the layout of text and images and adding animation and navigation buttons. The material expert gave cometary that in general, the material was complete, accurate, and the presentation of the material was good. The material expert gave suggestions that the worksheet activity was expected to reflect a more complex STEM learning, need to add some examples and use more up to date references. The revision of the material expert’s advice is to add several examples of microbial species and up to date references that have been included in M-STEM. Practitioners commented that M-STEM was very good and worthy of being used as a support for the teaching and learning process in microbiology learning. Practitioners provide suggestions, namely procedures for practicum activities in the minilab menu should be equipped with information on whether the practicum is done in groups or individually, and on the test menu, questions can be added in the form of essays. The revision of the practitioner’s suggestion is to add an instruction sentence to the minilab feature, namely the minilab activity carried out in groups, and the essay questions to be enriched in the ebook considering the difficulties in the correction system when displayed on M-STEM which can see the live value.

Main field testing, M-STEM was tested on the department of biology education students at IKIP Budi Utomo who were taking microbiology learning to determine the readability of M-STEM in microbiology learning. The results of the M-STEM readability test can be seen in Table 5.

Table 5 shows that the average value of the M-STEM validity from the readability aspect was 88.82% (very valid criteria). M-STEM is easy to use and operate by students so that students are interested in and enthusiastic about learning independently. The composition of the material contained in M-STEM is systematic and easy to understand because it uses simple and clear language.
### Table 5. The results of the M-STEM readability test

| No | Item                                                                 | Validity Value (%) | Criteria         |
|----|-----------------------------------------------------------------------|--------------------|------------------|
| 1  | The identity (title and author name) of M-STEM is very clear          | 90.00              | Strongly valid   |
| 2  | The menu buttons on M-STEM are easy to operate                        | 86.25              | Strongly valid   |
| 3  | The menu and sub-menu features on M-STEM help make it easier to move from one menu to another | 90.00              | Strongly valid   |
|    | The content on M-STEM helps make it easier to move from one menu to another which is presented in a very complete manner (material text, worksheets, mini tabs, materials, ebook, mini quiz, tests of critical thinking skills and communication skills in the form of self-assessments) | 93.75              | Strongly valid   |
| 4  | The availability of concept maps in M-STEM provides easy assistance in understanding the concept of microbiology | 90.00              | Strongly valid   |
| 5  | The content of the material menu on M-STEM is complete and systematic | 87.50              | Strongly valid   |
| 6  | The illustration of images on M-STEM can help students understand the concept | 83.75              | Strongly valid   |
| 7  | The usefulness of M-STEM is clear                                    | 87.50              | Strongly valid   |
| 8  | The menus and sub-menus at M-STEM can help students operate and use them as learning media | 82.50              | Strongly valid   |
| 9  | The worksheet menu on M-STEM helps activate classroom learning both independently and classically | 87.50              | Strongly valid   |
| 11 | Worksheets on M-STEM contain issues that are close to life and the role of technology as related to materials | 86.25              | Strongly valid   |
| 12 | Worksheets on M-STEM reflect STEM (Science, Technology, Engineering, and Mathematics) learning | 87.50              | Strongly valid   |
| 13 | The availability of an ebook menu on M-STEM which contains more complete and comprehensive material | 86.25              | Strongly valid   |
| 14 | The availability of a mini quiz menu at M-STEM can develop students' critical thinking and communication skills | 93.75              | Strongly valid   |
| 15 | The form of questions on the test reflects questions with critical thinking skills | 90.00              | Strongly valid   |
| 16 | The communication skills test menu in the form of self-assessment on M-STEM can develop student communication skills | 86.25              | Strongly valid   |
| 17 | The form of questions in self-assessment reflects questions that measure students' communication skills | 85.00              | Strongly valid   |
| 18 | The minilab menu at M-STEM helps students understand and prove the concept of microbiology through experiments | 83.75              | Sangat Valid     |
| 19 | Minilab at M-STEM raises issues related to the surrounding environment and the use of technology | 95.00              | Strongly valid   |
| 20 | The instructions for working with questions on the test menu on M-STEM are easy to understand | 90.00              | Strongly valid   |
| No | Item                                                                 | Validity Value (%) | Criteria          |
|----|----------------------------------------------------------------------|--------------------|-------------------|
| 21 | The language used in the test questions on M-STEM is easy to understand | 90.00              | Strongly valid    |
| 22 | The form of questions on the M-STEM test helps students measure their respective critical thinking skills | 91.25              | Strongly valid    |
| 23 | The form of questions on self-assessment on M-STEM helps students measure their respective communication skills | 90.00              | Strongly valid    |
| 24 | The availability of the live score feature makes students feel challenged and be more careful and prepare themselves before working | 90.00              | Strongly valid    |
| 25 | The existence of M-STEM being studied can lead to linkages to learn it | 88.75              | Strongly valid    |
| 26 | M-STEM learned can lead to independence in learning                  | 87.50              | Strongly valid    |
| 27 | M-STEM used in microbiology learning can improve critical thinking and communication skills | 86.25              | Strongly valid    |
| 28 | The material on M-STEM is relevant and supportive in microbiology learning | 93.75              | Strongly valid    |
| 29 | The composition of material contained on M-STEM is systematic and easy to understand | 90.00              | Strongly valid    |
| 30 | Learning activities on M-STEM can increase student motivation        | 91.25              | Strongly valid    |
| 31 | Learning with M-STEM can make it easier for students to study microbiology material | 90.00              | Strongly valid    |
| 32 | The worksheet feature contains activities that are in accordance with STEM (Science, Technology, Engineering, and Mathematics) learning | 86.25              | Strongly valid    |
| 33 | The mini quiz menu and tests on M-STEM can measure your level of understanding of the concepts being studied | 87.50              | Strongly valid    |
| 34 | M-STEM which is supported by text, images, videos, and instrumental background music helps in understanding the concept of microbiology | 95.00              | Strongly valid    |
|    | The average of validity value                                         | 88.82              | Strongly valid    |

Operational product revision, students commented that M-STEM is very good, suitable for 21st-century learning, M-STEM is very attractive to learning, easy to access for independent study, and M-STEM can inspire in the development of learning media. Students give suggestions to add more pictures related to the material. The revision given to this suggestion is to add more images to M-STEM.

**DISCUSSION**

The results of this research indicate that students and lecturers need learning media such as M-STEM in microbiology learning so that students can easily understand the concept of microbiology, lecturers can easily convey microbiology material to students, and both together can achieve learning outcomes. Multimedia is a learning media that can help students in learning such as understanding concepts (Apriyanti, Nur, Rahim, & Shaharom, 2017; Morris & Lambe, 2017; Kareem, 2018; Delima, Warsono, Supahar, & Jumadi, 2018; (Rosamsi, Miarsyah, & Ristanto,
Multimedia can make learning more effective because the interaction between lecturers and students increases so that it is easier for lecturers to convey subject matter to students, make the learning process focus on learning outcomes, and make students more enthusiastic and motivated in learning (Almara’beh et al., 2016; Kaur, Sharma, & Singh, 2015; Hidayati & Irmawati, 2019; Leow & Neo, 2014).

The M-STEM design is attractive in terms of features and is easily accessed by students anytime and anywhere using a laptop or mobile phone. Good multimedia is multimedia that can increase the attractiveness of students to learn (Wang, Sun, & Li, 2019; Prayitno & Hidayati, 2017b). M-STEM is designed very attractively, which includes learning outcomes, text materials, pictures, videos, audio, worksheets, mini quiz, min labs, ebook, tests, and live scores. Hidayati & Irmawati (2019) and Siagian, Mursid, & Wau (2014) argue that multimedia that is interesting and effective for learning is multimedia that contains a lot of content such as learning outcomes, text materials, images, videos, audios, approach-based worksheets, ebook, tests, and live scores. Multimedia worksheets can make students more active in learning (Kopniak, 2018). Furthermore, effective multimedia is multimedia that is easily accessed by students for learning such as being easily accessible with mobile phones (Ahmed, Salman, Malik, Streimikiene, Soomro, & Pahi, 2020; Hidayati & Irmawati, 2019; Prayitno & Hidayati, 2017a). One of the applications used to make multimedia so that it is easily accessed using a cellphone is the Adobe Flash Player (Septiani, Rejekiningstih, Triyanto, & Rusnaini, 2020).

M-STEM is strongly valid in the media aspect. M-STEM is designed with visualization, design, typography, and illustrations that attract students. Students will be interested and motivated to learn when using multimedia with interesting features (Xu, 2017; Koseoglu & Efendioglu, 2015). Complete multimedia features including text, images, videos, music, google form links, navigation buttons, awards, and animations (Hartoyo & Gafur, 2019). Raaijmakers, Baars, Schaap, Paas, Merriënboer, & Gog, (2018) argued that visualization and design in multimedia is an important part of attractiveness as a learning medium. The attractiveness of learning media is able to stimulate students to learn information contained in the multimedia (Sadikin, Johari, & Suryani, 2020). The navigation buttons, illustrated images, and videos on the M-STEM are easy to operate. This will make it easier for lecturers and students to access information on M-STEM. Nurrohmah, Putra, & Farida (2018) argued that the form of multimedia must be easy to use in the learning process. User friendly is one of the requirements for the fulfillment of good learning media (Himschoot, 2012).

M-STEM is strongly valid in the material aspect. M-STEM contains valid material and accountable criteria. The truth of the concept contained in multimedia plays a very important role in achieving learning outcomes and avoiding failure in learning (Azizah, Kusumaningtyas, & Anugraheni, 2018; Hidayati & Irmawati, 2019). The presentation of material on M-STEM was carried out from simple to complex. Systematic delivery of knowledge will make it easier for students to link the concepts they have with the concepts they have just received. This will stimulate students to be able to think at higher levels (Korres & Tsami, 2010). M-STEM was developed to achieve the novelty aspect as a media. This can be seen from the STEM approach used in the worksheet feature. The eight activities contained in the worksheet include defining the problem, relating it to real life, planning and conducting investigations, analyzing and interpreting the data obtained, making a provisional conclusion, designing alternative problem solutions, discussing solutions obtained, and evaluating and communicating. M-STEM can create a learning process that can develop 21st-century skills in accordance with current educational developments (Hidayati & Irmawati, 2019). The tests on M-STEM are prepared based on indicators of critical thinking and communication skills so that M-STEM can be used to measure the students' skills.
Learning media must be equipped with an evaluation in order to measure student knowledge (Fatimah, Suryani, & Yamtinah, 2018). M-STEM is categorized as strongly valid from the utility aspect of microbiology learning. M-STEM was developed according to the learning outcomes in the curriculum used. The material arranged based on the curriculum will be in accordance with the standard of learning content. The standard of learning content is one of the benchmarks for achieving the competency standard of graduates (Kemenristekdikti, 2018b). The readability test results categorize that M-STEM is strongly valid. M-STEM is easy to use, the material content is very systematic and easy for students to understand. Song & Bonk (2016) argues that learning media that can be used in learning are learning media that have standard validity criteria.

CONCLUSION
M-STEM in microbiology learning is declared to be strongly valid in the aspect of media (88.36%), material (97.00%), usefulness in microbiology learning (99.49%), and readability (88.82%) so that M-STEM can be used in microbiology learning. In addition, M-STEM is a learning media in microbiology learning that can help students understand microbiology concepts easily. Furthermore, M-STEM can be recommended for further research in order to determine its effectiveness in microbiology learning.

ACKNOWLEDGMENT
Thank you to the Ministry of Education and Culture, Higher Education Service Institutions in Region VII, and the Department of Research and Community Service of IKIP Budi Utomo has become a sponsor in my research.

REFERENCES
Ahmad, I. (2018). Proses pembelajaran digital dalam era revolusi industri 4.0. Retrieved from http://kimia.unnes.ac.id/v1/wp-content/uploads/2018/02/V11-Dirjen-Belmawa-IA_Belmawa-Rakernas-Ristekdikti-Medan-Final-16-01-18.pdf
Ahmed, R.R., Salman, F., Malik, S.A., Streimikiene, D., Soomro, R.H., & Pahi, M.H. (2020). Smartphone use and academic performance of university students: a mediation and moderation analysis. Sustainability (Switzerland), 12(1), 1-28. Retrieved from https://doi.org/10.3390/SU12010439
Almara’beh, H., Amer, E. F., & Sulieman, A. (2016). Effectiveness of multimedia learning tools in education. International Journal of Advanced Research in Computer Science and Software Engineering, 5(12), 761-764. Retrieved from https://www.researchgate.net/publication/290429349_The_Effectiveness_of_Multimedia_Learning_Tools_in_Education
Apriyanti, N., Nur, R.I., Rahim, S.S.A., & Shaharom, M.S.N. (2017). The Effectiveness of using multimedia in teaching physics to gauge student learning outcomes in the senior high school in indonesia. International Research Journal of Education and Sciences (IRJES), 1(2), 11-14. Retrieved from http://www.mastree.info/wp-content/uploads/2017/10/IRJES-VOL-1-ISSUE-2-ARTICLE-3-1.pdf
Azizah, Z.F., Kusumaningtyas, A.A., & Anugraheni, A.D. (2018). Validasi preliminary product fung-cube pada pembelajaran fungi untuk siswa sma. Jurnal Bioedukatika, 6(1), 15-21. Retrieved from https://doi.org/10.26555/bioedukatika.v6i1.7364
Bybee, R.W. (2011). Scientific and engineering practies in k-12 classrooms: understanding a framework for k-12 science education. handbook of conversation design for instructional applications. Retrieved from https://doi.org/10.4018/978-1-59904-597-9.ch013
Delima, E., Warsono, Supahar, & Jumadi. (2018). The importance of multimedia learning modules (mlms) based on local wisdom as an instructional media of 21st century physics learning. *Journal of Physics: Conference Series, 1097*(1), 1-11. Retrieved from https://doi.org/10.1088/1742-6596/1097/1/012018

Fajrina, S., Lufri, & Ahda, Y. (2020). Science, technology, engineering, and mathematics (stem) as a learning approach to improve 21st century skills: a review. *International Journal of Online and Biomedical Engineering (ijOE), 16*(7), 95-104. Retrieved from https://doi.org/10.3991/ijoe.v16i7.14101

Fatimah, A.W.N., Suryani, N., & Yamtinah, S. (2018). The development of critical thinking test based on higher-order thinking pisa version in the historical learning at senior high school. *International Journal of Multicultural and Multireligious Understanding, 5*(2), 136-144. Retrieved from https://doi.org/10.1080/17565714.2020.1748896

Hartojo, & Gafur, A.D. (2019). Development and testing of biology learning multimedia effectiveness. *Journal of Physics: Conference Series, 1233*(1), 1-13. Retrieved from https://doi.org/10.1088/1742-6596/1233/1/012004

Hidayat, Z., Sarmi, R.S., Fisika, M.P., & Padang, U.N. (2020). Efektivitas buku siswa Ipsa terpadu dengan tema energi dalam kehidupan berbasis materi lokal menggunakan model integrated untuk meningkatkan kecakapan abad 21. *JEP (Jurnal Eksakta Pendidikan), 4*(1), 49-56. Retrieved from https://doi.org/10.24036/jep/vol4-iss1/415

Hidayati, N., Irmawati, F. (2019). Developing digital multimedia of human anatomy and physiology material based on stem education. *JPBI (Jurnal Pendidikan Biologi Indonesia), 5*(3), 497-510. Retrieved from https://doi.org/10.22219/jpbi.v5i3.8584

Kaur, R., Sharma, K., & Singh, S. (2015). Effectiveness of multimedia approach on the academic achievement of class 8th students in english. *International Journal of Applied Research, 1*(9), 467-471. Retrieved from http://www.allresearchjournal.com/archives/2015/vol1issue9/PartH/1-9-127.pdf

Kemenristekdikti. (2018a). *Mempersiapkan sdm indonesia di era industri 4.0.* Retrieved from http://sdgcenter.unpad.ac.id/wp-content/uploads/2018/09/Kemenristekdikti-Mempersiapkan-SDM-Indonesia-di-Era-Industri-4.0.pdf

Kemenristekdikti. (2018b). Standar nasional pendidikan tinggi, *Produk Hukum, 1*(49), 1-109. Retrieved from http://www.kopertis12.or.id/wp-content/uploads/2014/06/permen_tahun2014_nomor049.pdf

Kennedy, T.J., & Odell, M.R.L. (2014). Engaging Students In STEM Education. *Science Education International, 25*(3), 246-258. Retrieved from 10.31932/jpbio.v5i2.879
http://www.icaseonline.net/sei/september2014/p1.pdf
Kopniak, N.B. (2018). The use of interactive multimedia worksheets at higher education institutions. Information Technologies and Learning Tools, 6(1), 116-129. Retrieved from https://doi.org/10.33407/itlt.v6i1.1887
Korres, K., & Tsami, E. (2010). Supporting the development of critical thinking skills in secondary education through the use of interdisciplinary statistics’ and mathematics’ problems. Journal of Interdisciplinary Mathematics, 13(5), 491-507. Retrieved from https://doi.org/10.1080/09720502.2010.10700716
Koseoglu, P., & Efendioglu, A. (2015). Can a multimedia tool help students’ learning performance in complex biology subjects?. South African Journal of Education, 35(4), 1-12. Retrieved from https://doi.org/10.15700/saje.v35n4a1169
Kozikoglu, I. (2019). Investigating critical thinking in prospective teachers: metacognitive skills, problem solving skills and academic self-efficacy. Journal of Social Studies Education Research, 10(2), 111-130. Retrieved from http://jsser.org/index.php/jsser/article/view/362/371
Leow, F.T., & Neo, M. (2014). Interactive multimedia learning: Innovating classroom education in a Malaysian university. Turkish Online Journal of Educational Technology, 13(2), 99-110. Retrieved from https://eric.ed.gov/?id=EJ1022913
Morris, N.P., & Lambe, J. (2017). Multimedia interactive e-books in laboratory bioscience education. Higher Education Pedagogies, 2(1), 28-42. Retrieved from https://doi.org/10.1080/23752696.2017.1338531
Nurrohmah, F., Putra, F.G., & Farida, F. (2018). Development of sparkol video scribe assisted learning media. Formatif: Jurnal Ilmiah Pendidikan MIPA, 8(3), 233-250. Retrieved from https://doi.org/10.30998/formatif.v8i3.2613
Prayitno, T.A., & Hidayati, N. (2017a). Pengembangan multimedia interaktif bermuatan materi mikrobiologi berbasis edmodo android. Bioilmi: Jurnal Pendidikan, 3(2), 86-93. Retrieved from https://doi.org/10.19109/bioilmi.v3i2.1399
Prayitno, T.A., & Hidayati, N. (2017b). Implementasi media pembelajaran edmodo pada mata kuliah mikrobiologi untuk meningkatkan hasil belajar kognitif mahasiswa. Prosiding Seminar Pend. IPA Pascasarjana UM, 2(1), 583-590. Retrieved from https://core.ac.uk/download/pdf/267023991.pdf
Raaijmakers, S.F., Baars, M., Schaap, L., Paas, F., Merriënboer, J., & Gog, T. (2018). Training self-regulated learning skills with video modeling examples: do task-selection skills transfer?. Instructional Science, 46(2), 273-290. Retrieved from https://doi.org/10.1007/s11251-017-9434-0
Rosamsi, S., Miarsyah, M., & Ristanto, R.H. (2019). Interactive Multimedia Effectiveness in Improving Cell Concept Mastery. Journal of Biology Education, 8(1), 56-61. Retrieved from https://doi.org/10.15294/jbe.v8i1.28154
Sadikin, A., Johari, A., & Suryani, L. (2020). Pengembangan multimedia interaktif biologi berbasis website dalam menghadapi revolusi industri 4.0. Edubiotik : Jurnal Pendidikan, Biologi Dan Terapan, 5(01), 18-28. Retrieved from https://doi.org/10.33503/ebio.v5i01.644
Septiani, A.N.S.I., Rejekningsih, T., Triyanto, & Rusnaini. (2020). Development of interactive multimedia learning courseware to strengthen students’ character. European Journal of Educational Research, 9(3), 1267-1279. Retrieved from https://doi.org/10.12973/ejer.9.3.1267
Siagian, S., Mursid, & Wau, Y. (2014). Development of interactive multimedia learning in learning instructional design. Journal of Education and Practice, 5(32), 44-51. Retrieved from https://www.iiste.org/Journals/index.php/JEP/article/view/16711
Song, D., & Bonk, C.J. (2016). Motivational factors in self-directed informal learning from online learning resources. *Cogent Education, 3*(1), 1-11. Retrieved from https://doi.org/10.1080/2331186X.2016.1205838

Van Rosmalen, P., Boyle, E.A., Van der Baaren, J., Kärki, A.I., & Aguado, Á.B. (2014). A case study on the design and development of minigames for research methods and statistics. *EAI Endorsed Transactions on Game-Based Learning, 3*(3), 1-9. Retrieved from https://doi.org/10.4108/sg.1.3.e5

Wahyuni, D. (2018). Peningkatan kompetensi guru menuju era revolusi industri 4.0. *Info Singkat (Kajian Singkat Terhadap Isu Aktual dan Strategis) Pusat Penelitian Badan Kehakian DPR RI, 10*(24), 13-18. Retrieved from https://berkas.dpr.go.id/puslit/files/info_singkat/Info_Singkat-X-24-II-P3DI-Desember-2018-218.pdf

Wang, H.H., Charoenmuang, M., Knobloch, N.A., & Tormoehlen, R.L. (2020). Defining interdisciplinary collaboration based on high school teachers’ beliefs and practices of STEM integration using a complex designed system. *International Journal of STEM Education, 7*(1), 1-17. Retrieved from https://doi.org/10.1186/s40594-019-0201-4

Wang, X., Sun, H., & Li, L. (2019). An innovative preschool education method based on computer multimedia technology. *International Journal of Emerging Technologies in Learning, 14*(14), 57-68. Retrieved from https://doi.org/10.3991/ijet.v14i14.10714

Widarti, H.R., Rokhim, D.A., & Syafrudin, A.B. (2020). The development of electrolysis cell teaching material based on stem-pjbl approach assisted by learning video: a need analysis. *Jurnal Pendidikan IPA Indonesia, 9*(3), 309-318. Retrieved from https://doi.org/10.15294/jpii.v9i3.25199

Widiawati, L., Joyoatmojo, S., & Sudiyanto. (2018). Higher Order thinking skills as effect of problem based learning in the 21st century learning. *International Journal of Multicultural and Multireligious Understanding, 5*(3), 96-105. Retrieved from https://ijmmu.com/index.php/ijmmu/article/view/223

Xu, X. (2017). Study on Effective using of multimedia teaching system and enhancing teaching effect. *International Journal of Emerging Technologies in Learning, 12*(6), 187-195. Retrieved from https://doi.org/10.3991/ijet.v12i06.7093

Yusnaini, & Slamet. (2019). Era revolusi industri 4.0: tantangan dan peluang dalam upaya meningkatkan literasi pendidikan. *Prosiding Seminar Nasional Program Pasca Sarjana Universitas PGRI Palembang, 1*(2 Januari 2019), 1073-1085. Retrieved from https://jurnal.univpgri-palembang.ac.id/index.php/Prosidingpps/article/view/2668

Zubaidah, S. (2018a). Mengenal 4c: learning and innovation skills untuk menghadapi era revolusi industri 4.0. In *2nd Science Education National Conference* (pp. 1-18). Retrieved from https://www.researchgate.net/publication/332469989

Zubaidah, S. (2018b). *Trend Penelitian pendidikan biologi. paper kuliah tamu di pendidikan biologi fkip universitas islam riau (Vol. 1)*. Riau. Retrieved from https://www.researchgate.net/publication/325809615