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Developing BTEM-Based Virtual Biology Laboratory to Improve Students' Critical Thinking Skills on the Concept of Bacteria

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a b s t r a c t

The Covid-19 pandemic that has hit the entire world has caused changes in learning patterns from classroom to virtual classroom activities, and this has caused biology teachers to experience problems when teaching material through direct practicum activities. There is a need for solutions that can facilitate practicum activities by developing a virtual laboratory application. This research develops a Virtual Biology Laboratory (VLab-Bio) application based on Biology, Technology, Engineering, and Mathematics (BTEM) that is feasible and practical to facilitate virtual lab work on the concept of bacteria. The application product produced from this research is expected to help students facilitate practicum activities and improve critical thinking skills on the concept of bacteria. The application produced from this research is expected to help students improve their critical-thinking skills and lab work on bacterial material. Akker development model was used with four stages of development: preliminary research, prototyping, summative evaluation, and systematic reflection and documentation. The research instrument consisted of tests of critical-thinking skills and non-tests in the form of observations of the learning process and student response questionnaires. The research data were analyzed qualitatively and quantitatively with the paired t-test. The results showed that the BTEM-based virtual laboratory developed was classified as valid and effective in improving students' critical-thinking skills with 78% effectiveness. Based on this research, it can be recommended that using a BTEM-based virtual laboratory can be used as a supplement in facilitating bacterial concept practicum activities. For further application development, it is hoped that the application can provide flexibility for students to develop their own practicum procedures in applications.

1. Introduction

In biology learning, lab work has a notable role in developing process and inquiry skills in students (Widowati et al., 2017). Biology teachers in schools sometimes do not carry out lab work for various reasons such as not having a representative laboratory, finishing learning materials, and having no time to prepare laboratory work for their students. Laboratory work has many benefits for students to generate their learning motivation in science, develop their necessary skills in conducting experiments, become a medium for learning scientific approaches, and support subject matter (Rustaman et al., 2003). The implementation of lab work is expensive and takes a long time (Widodo et al., 2017). There should be an alternative medium to facilitate laboratory work that is difficult for teachers to carry out directly by using computer technology in the form of a virtual laboratory (Flowers, 2011).

The virtual laboratory has various definitions, one of which is stated by Jaya (2013) as an interactive environment for creating and conducting simulated experiments. Another definition of a virtual laboratory is a computer program that allows students to perform simulated experiments via websites or stand-alone apps (Bajpai & Kumar, 2015). This definition is reinforced by Woodfield (2005), stating that a virtual laboratory simulates a real laboratory environment and process as a learning environment that enables students to convert their theoretical knowledge into practical knowledge through experimental activities. It can be concluded that a virtual laboratory is a computer simulation program designed like a real laboratory environment to practice a concept of learning material with a specific purpose.

This lab has many benefits, e.g., it saves funds for building laboratory infrastructure, is free from the use of hazardous substances or materials, can be used by many people at the same time, and is accessible anywhere and anytime (De Jong & Van Joolingen, 1998; Sypsas & Kalles, 2018). In the current Covid-19 pandemic, using a virtual laboratory is the most effective solution for teachers to facilitate student lab work.

The findings of Tatli & Ayas (2010) on virtual laboratory use showed that this app was very effective and useful in facilitating students in doing lab work with limited tools and materials. Muhamad et al. (2012) further concluded that using an integrated virtual laboratory in the learning scenario was very useful in facilitating learning on cell, mitosis, and cloning materials. Similarly, Suryanti et al. (2019) revealed that virtual laboratory use could promote concept mastery in molecular biology courses. The research shows that the use of virtual laboratory can improve students' concept mastery, attitudes, achievements, and higher-order thinking skills (HOTS) (Tüysüz, 2010; Gunawan et al., 2017; Gunawan & Liliasari, 2012; Setiawan et al., 2018; Sutarno et al., 2018; Alneyadi, 2019).

Although virtual laboratory has many benefits, the real laboratory is still better; however than virtual laboratories because they directly practice hand-on skills and science process skills (Rustaman et al., 2003), in some aspects, the virtual laboratory is superior, because it can be repeated and minimizes risk and can be accessed anywhere (Stuckey-Mickell & Stuckey-Danner, 2007). From this research, it is concluded that the use of virtual laboratory can complement real laboratory activities. The virtual laboratory can be used as (a) a simulation model before direct practice, (b) a substitute for expensive or hazardous materials or tools, and (c) an alternative to direct practicum activities (Sypsas & Kalles, 2018).

According to Dewi and Prasetiyo (2015), one of the concepts of biology learning at the high school level that is difficult to practice directly in the laboratory is a practicum on eubacteria, especially bacterial staining and counting bacterial colonies. This is because most schools do not have sufficient laboratory equipment for many students. The development of a virtual biology laboratory integrated with biology, technology, engineering, and mathematics (BTEM) can help students develop necessary practical skills. Cheong and Koh's findings concluded that the use of integrated engineering and virtual mathematics laboratory was proven to improve student learning outcomes (Cheong & Koh, 2018).

BTEM-based virtual biology laboratory is a virtual lab work application as an alternative and a complement to direct lab work. This application can be run on PC and Android platforms. Virtual biology laboratory was developed based on BTEM on the concept of bacteria for high school level by presenting virtual lab work for observing the making of bacterial culture media, bacteria, counting bacterial colonies, and staining gram-positive and gram-negative bacteria. BTEM is part of the New Biology for the 21st century, which integrates multi-disciplines, such as engineering, computer science, physics, chemistry, and mathematics (NRC, 2009; Zubaidah, 2019). BTEM-based virtual biology laboratory is expected to facilitate skill development in biology, technology, engineering, and mathematics for stimulating students' critical-thinking skills through the practical simulation activities presented.

This research has a novelty aspect from virtual laboratory research that has been developed previously because it integrates the BTEM concept as a component of application development (see Table 5). In the current covid-19 situation, a solution is needed to facilitate student practicum activities online through a virtual laboratory. Therefore the aim of this study is to develop an effective virtual laboratory to facilitate learning activities and biology lab work so that it can facilitate students to develop level thinking skills. Particularly critical thinking, which is one of the essential skills of the 21st century.

2. Method

This study uses a research and development (R&D) approach from Akker (2009), which consists of four stages, namely the preliminary research stage, which is carried out through preliminary data mining activities on the research object; prototyping stage is carried out through the development of a virtual laboratory prototype in the form of a beta version of the application; summative evaluation is carried out through the implementation of the BTEM-based virtual laboratory application in classroom learning, and systematic reflection and documentation is a reflection and research documentation in this case illustrated through two main parts of research, namely the virtual laboratory application storyboard and research implementation activities.

The applications used in developing this virtual laboratory were Adobe Flash and Constructed 3. This development research was carried out in class X of MA “AR” Majalengka Regency comprising 20 students as the research subjects through purposive sampling technique. The research instrument consisted of an expert assessment sheet, a questionnaire sheet, an observation sheet, and a test of critical thinking skills on bacteria's concept. The data were analyzed using qualitative data analysis techniques through data collection stages, data reduction, data presentation, and the final step is drawing conclusions. Quantitative data were analyzed using SPSS 24 for Windows. Previous quantitative data were subjected to prerequisite tests, and the conclusion was that the data were normal and homogeneous, so that they were tested using the paired t-test.

3. Result and Discussion

There are four stages in this research; they are (1) preliminary research, (2) prototyping, (3) summative evaluation, and (4) systematic reflection and documentation. Stages (3) and (4) were performed when the product was in the field implementation phase. The stages are described as follows.

Preliminary research

Preliminary research aims to find out the problems of biology learning faced in schools that are the research targets. Due to the Covid-19 pandemic, the preliminary research was carried out through online interviews with the teachers and students and document studies from the data provided by the school. The following are the preliminary research findings on the process of learning activities and practicum activities before and during the Covid-19 pandemic.

Table 1. Preliminary Research Findings

No	Findings	Information
1	Biology learning activities	It was implemented through face-to-face activities using various types of methods and media, especially PowerPoints. During a pandemic like now, it is implemented using a blended learning system using various Learning Mobile System applications, especially Google Classroom.
2	Biology laboratory facilities	The available tools and materials are not sufficient for a large number of students; besides that, they do not have a laboratory assistant who is in charge of managing and administering laboratory assets.
3	Laboratory safety system	Not yet equipped with an adequate security system such as a fire extinguisher
4	Practical activities	It was not yet scheduled and only implemented on a concept that supplies adequate tools and materials. For concepts that require tools and materials that are not yet available, practicum activities are not implemented and facilitated through video simulations.

The results showed in Table 1 that several problems needed to be followed up. Finally, it was concluded that the main problem during online learning at school was the difficulty of doing biology lab work directly due to limited tools and materials. Referring to these results, the researchers conclude that a virtual laboratory needs to be developed to facilitate student lab work, especially during the current pandemic.

Prototype stage

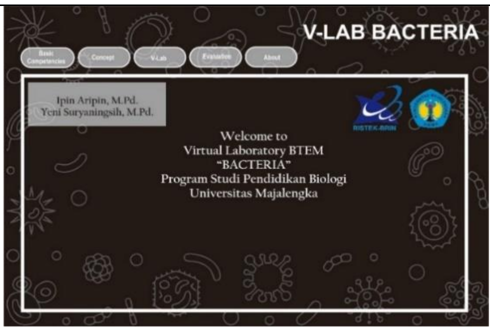
This stage is based on the need analysis carried out on the curriculum's main components, syllabus, learning materials, and student characteristics. The need assessment results were then derived as a reference in the development of the virtual laboratory in the form of flowcharts and storyboards. A virtual laboratory user guide module and learning support materials were also developed as supplements in this phase. The virtual laboratory prototype developed then entered the alpha phase (expert judgment) involving media and content experts. The results of the expert judgment are presented in the following Table 2.

Table 2. Expert judgment on BTEM-based virtual laboratory prototype

No	Expert	Score	Remark
1	Media	73.67	Good
2	Content	77.66	Good

Based on the expert judgment results, the prototype was feasible for use with several revisions, such as improving the less attractive display design, correcting errors in writing scientific names, and re-checking hyperlinks between slides. Detailed results of the improvements based on expert suggestions are presented as follows in Table 3.

Table 3. Advice expert judgment on BTEM-based virtual laboratory prototype

No	Before	After
1		
2		Writing the name of the bacteria as in the application has not followed the correct scientific nomenclature, so that e-coli needs to be fixed to *E. coli*, lactobacillus repaired *Lactobacillus*.

Summative evaluation

This stage is part of the implementation of BTEM-based virtual laboratory as the final product. The prototype has gone through several stages (expert judgment and limited trials) and been improved before the implementation, resulting in the final product that is feasible for use in learning. The summative evaluation stage was carried out by providing tests and questionnaires in one of the schools implementing a blended learning system. The results of the students' critical-thinking skills test on bacteria material are shown in the following Table 4.

Table 4. Test results for critical thinking skills concepts of bacteria

Mean			Paired t-test	% Completeness	Information
Pre-test	**Post-test**	**N-gain**			
58,00	78,20	0,56	0.000	78%	Effective

Statistical testing using paired t-test obtained Sig. 0.000 indicates a significant difference in test results, which means that students' critical thinking skills on the pre-test and the post-test are significantly different. The test results in Table 4 above show that, in general, the N-gain of the students increased in the moderate category and their learning completeness was 78%, meaning that the application developed is effective. For the student response questionnaire to using the BTEM-based virtual laboratory, 84.56% of students responded enthusiastically to this media in learning, and it became an alternative solution for lab work during the current pandemic.

Systematic reflection and documentation

This is the final stage in the development of BTEM-based virtual laboratory developed by Akker (2009). This stage contains reflection and documentation of the virtual laboratory development activities from the initial stage to implementation. At the implementation stage, it began with an introduction to using a virtual laboratory and the learning indicators to be achieved, followed by the implementation of learning using the application. The Systematic Reflection and Documentation stages present reflections and documentation of research activities carried out from the beginning to the end. Here are two essential parts of this research activity, namely the application storyboard and the implementation of the following research results.

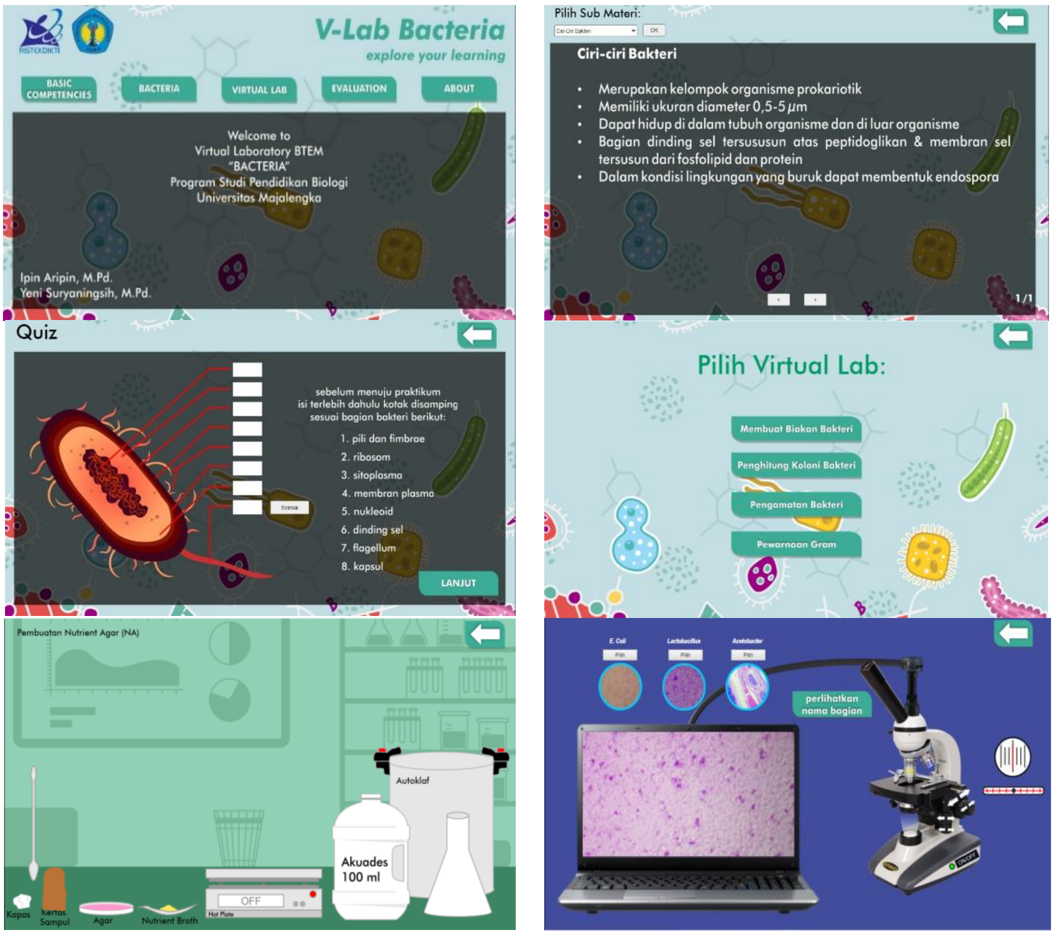


Figure 1. Systematic reflection and documentation virtual laboratory application menu based on BTEM

The Systematic Reflection and Documentation stages also describe how the research implementation process was carried out. In its implementation, this research was carried out through direct meetings at the initial meeting as a form of socialization on how to use the application to students. The next meeting is conducted online, where students are given a virtual laboratory support module to study independently with teaching teachers and researchers' guidance.

BTEM-based virtual laboratory developed consists of four lab activities, namely the making of bacterial culture media, calculation of bacterial colonies, bacterial observation, and gram staining. The BTEM components for the development of virtual laboratory refer to Osman et al. (2013) as follows in Table 5.

Table 5. BTEM components in VLab-Bio

BTEM	Remark
Biology (the core of scientific content)	Bacteria learning content at the revised 2013 Curriculum for Senior High School includes definition, characteristics of bacteria, bacterial staining, way of life of bacteria, adjustment of bacterial life, reproduction, classification, role, breeding, and handling of bacterial hazards. The practicum content developed in VLab-Bio includes the making of bacterial culture media, calculation of bacterial colonies, bacterial observation, and gram staining.
Technology (support for the learning process)	Using technology to support the learning process and biological research.
Engineering (solution to solve a problem)	Finding creative problem-solving solutions based on scientific principles.
Mathematics (computational/modeling tool)	Identifying, reading, and communicating in the form of data generalizations in tables and charts.

In essence, BTEM is closely associated with STEM; in other words, BTEM is a modified STEM with a scientific discipline that is integrated into biology. According to Hiong & Osman (2015), BTEM can integrate 21st century skills into the biology curriculum more effectively. The concept of BTEM put forward by Osman et al. (2013) essentially emphasizes inquiry discovery, which aims to provide a framework for teaching inquiry discovery, which emphasizes the active discovery of biological knowledge by students (Hiong & Osman, 2013).

Based on the results of this research, it is known that the use of the BTEM-based virtual laboratory developed has met the criteria for use according to the results of expert judgment. The implementation of BTEM-based virtual laboratory showed an increase in students' average critical thinking skills of 0.58 (moderate) with an effective level of 78%. Increasing critical thinking skills through the use of BTEM-based virtual laboratories based on the results of research that has been carried out is known for several reasons, namely (1) the virtual laboratory application presents practicum simulations that train students to think and analyze through virtual practicum simulation activities; (2) the virtual laboratory application is also equipped with simulations and videos so that it can stimulate students to think; (3) students are also stimulated to think and practice through the material, and practice questions in the application and manual modules as a supplement to the virtual laboratory application; (4) the use of a virtual laboratory application which is packaged attractively and interactively encourages interest and motivation for students to explore and re-study the material. This is reflected in the results of a questionnaire which states that 84.56% of students stated that the virtual laboratory developed was very attractive to students; (5) virtual laboratories are also media that are rarely used by biology teachers in the classroom or online learning, teachers often use media in the form of power points or videos from YouTube, which is of course only one way, unlike virtual laboratories which are designed to be able to interact in two directions with providing stimulus and response. This is in line with the opinion that BTEM can enhance students' creativity and HOTS (Osman et al., 2013; Hiong & Osman, 2015). Another research found that the use of a virtual laboratory could improve students' HOTS, such as critical thinking skills and creativity, on the concept of invertebrates (Widowati et al., 2017; Ramadhan 2017; Sapriadil et al., 2019; Malik et al., 2019; Suryaningsih et al., 2020). Mastering critical-thinking skills is essential today because it is closely related to one's success in education, a competency needed by students in facing the challenges of the 21st century (Halpern, 2014; Moeti et al., 2017).

Through the use of BTEM-based virtual laboratory, student psychomotor is also trained with simulations of using manipulative laboratory tools in the form of computer programs with the hope that they can practice inquiry skills (Zion et al., 2004). The research study by Dyrberg (2017) found that the use of virtual laboratory can improve students' attitudes, motivation, and self-efficacy. The use of a virtual laboratory at the beginning of learning can also improve students' understanding and thinking skills (Toth et al., 2014). The responses to the use of BTEM-based virtual laboratory show a positive result (84.56%). The use of appropriate and engaging learning media can arouse students' learning interest, which can be influenced by internal and external factors (Syah, 2011).

4. Conclusion

Based on the results of the study, it can be concluded that the BTEM-based virtual laboratory biology developed meets the appropriate criteria for use according to the assessment of media experts and biological content experts in a good category. The implementation results show that the application of this application can facilitate the improvement of students' critical thinking skills on the concept of bacteria in the medium category. Based on the research results, it produced a recommendation that this application could be used as a complement to teaching the concept of bacteria at the high school level by adding more virtual practicum features such as making culture and virtual bacterial culture media. For the development of the virtual laboratory application, it is further suggested that the application facilitate students to design their practicum activity procedures so that students can modify and train students' critical thinking skills better.

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