Virtual laboratory for enhancing students’ understanding on abstract biology concepts and laboratory skills: a systematic review

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Abstract. The virtual laboratory has been widely used in biology learning at all levels of education, but it remains a challenge for countries with technological shortages. Many biological concepts were abstract and difficult to be understood through simple explanation or even difficult to do in a laboratory. Utilization of virtual labs in biology learning, especially in higher education needs to be reviewed about the characteristics of contents, and function and its efficiency to assess the specific variables. Thus, this systematic review was carried out to analyze research articles published from 2010 to 2018. The articles were selected using the PRISMA. The articles were obtained from Google Scholar, the Science Direct, and the Journal of Science Education, ERIC, and Journal of Biological Education. In total, 199 articles were found. The general analysis was conducted. The results yielded 47 articles to be further analyzed by looking at the content and results of the study. Twenty-three articles were obtained and analyzed. Journal content analysis was focused on the selected topic, the dependent variables, sample size, effect size, research design, data collection techniques, research objectives, and the results. Cell or molecular biology was the most widely used topics in the virtual laboratory. Students’ conceptual understanding was the most studied variable, some studies examine students’ affective and psychomotor skills, but only a few studies examine the learning process. Most biology virtual labs were developed using the Adobe Flash Player application with 3D animation. The results suggested for further research to develop a virtual biology lab that is more inquiry-based, and capable of assessing students’ conceptual change and science process skills which not have been widely studied.

1. Introduction

The virtual laboratory is a relatively new media for biology learning, although it had been used in many other fields of science [1]. The virtual laboratory (V-Lab) was first used in biology learning to help students learn an abstract and difficult-to-visualize topics (i.e. Cell and DNA) [2]. Animation-based V-Lab for biology was created by Barnea and Dori in 2000 and was redeveloped into three-dimensional animation by Sanger [3]. The virtual laboratory (V-Lab) is the representation of a virtual-based simulation and animation laboratory to present an interactive virtual environment for education [4]. Virtual Labs provide important experiences for individual students as additional material to prepare for manual laboratory or provide experiences similar to the manual laboratories [3]. The V-Lab also useful to present science as a process and to emphasize scientific concepts [5].

V-Lab provides opportunities for students to build their understanding of the environment, objects, and phenomena. Students can observe and manipulate objects, variables, and processes. They can also understand the relationship between science theory, empirical evidence, and discoveries [6].
has been widely used to support the learning process especially as the effort to create authentic laboratory activities in biology learning.

Empirical studies have shown the effect of V-Lab on cognitive and affective learning outcomes in science learning, but there were few studies about the extent to which virtual laboratories were being used in biology learning. Earlier studies stated the importance to discuss various aspects of science learning, especially the specific characteristics which relevant to the field of subjects [7-9]. This research was aimed to find out the use of virtual laboratories as the learning media for biology and to find out the effect of virtual laboratory use on student learning achievement.

Based on the previous descriptions, some research questions can be formulated about the use of the virtual laboratory in biology learning, such as:

a. What is the extent of virtual laboratories utilization in biology learning, includes the topic often used by researchers?

b. What the characteristics of V-labs for biology?

c. What the effects of V-labs on the cognitive, psychomotor, and affective domains of students in biology learning?

2. Methods

This systematic review included the research articles about virtual laboratories in biology education published from 2010 to 2018. The articles were selected using the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) approach from [10]. The articles were obtained from Google Scholar, the Science Direct, and the Journal of Science Education, ERIC (Educational Resources Information Center), and Journal of Biological Education. Twenty-eight articles were obtained from articles with Google Scholar using keywords: “biology education” “biology learning” “Virtual laboratory” and “simulation.” Twenty-nine articles were obtained from the Journal of Biological Education. Twenty-six articles were yielded from Science Direct with the following keywords: “biology education” “Biology learning” “Virtual laboratory” and “undergraduate.” One-hundred and sixteen articles were obtained from ERIC databases with the categories: “Since 2010,” “biology,” “Reports Research,” “Undergraduate Student,” and “CBE-Life Sciences Education.”

In total, 199 articles were found. The general analysis was conducted to confirm if the articles were: a. research reports, b. applied in biology learning, c. using a virtual laboratory, d. applied in higher education, and e. issued from 2010 to 2018. The results yielded 47 articles to be further analyzed by looking at the content and results of the study. Journal content analysis was focused on the selected topic, the dependent variables, sample size, effect size, research design, data collection techniques, research objectives, and the results.

3. Result and Discussion

3.1 The Topic Coverage

Content analysis showed the cell, molecular biology, and introductory biology was the most widely used topic in the virtual laboratory. Few researchers used virtual laboratories for interdisciplinary science or topics (Figure 1).

Several topics were applied using virtual laboratories, such as the cell, molecular biology, ecology, introductory biology, evolution, biotechnology, genetics, and interdisciplinary topics (e.g. Biochemistry). The results showed the introductory biology (including biodiversity), and the body systems as the most used topics for virtual labs (n=7). The Cell or Molecular biology has 5 articles, the biotechnology was 2 articles, biochemistry was one article, ecology two articles, and two articles for the mechanism of the evolution (Figure 1).
There are several reasons researchers were interested in the topic above. Some topics were considered as abstract (i.e. cell, DNA), dynamic (i.e. protein synthesis, cell division), difficult to visualize in real life (i.e. molecule biology, viruses), and comprised of complex relationships between elements (i.e. ecological systems). The interdisciplinary topics were rarely used by researchers in virtual laboratories. The examples of interdisciplinary topics which have used virtual labs were biochemistry (integration between biological and chemical sciences) and biophysics (integration between biological and physical sciences).

3.2 The Measured Variables

The biological conceptual understanding was the most prominent variable to be researched, some study focused on the students’ affective and skills, only a few focused on the learning process. The biological conceptual understanding was viewed from the students’ correctness and comprehensive understanding of the biological concepts. Some studies showed the V-labs have both positive and negative effects. Study by [11] concluded 90% of the students experienced improvement their understanding of genetics. Highest gain was observed on the low academic students, which their scores were improved from 44% to 68%, the significant improvement of 24%, $t (85) = 14.42$, $p < 0.001$; $d = 3.35$. The middle achievers were improved as much as 11%, $t (100) = 10.87$, $p < 0.001$; $d = 1.45$. And the higher achievers were improved as much as 3%, $t (112) = 3.69$, $p < 0.001$; $d = 0.36$. Some studies stated there were no significant effects of V-labs on students’ conceptual understanding [4,12,13]. The V-labs accompanied by direct hands-on activities were more effective than the traditional laboratories or v-labs alone [14-16].

Students’ laboratory skill was another variable to be researched. Laboratory skill is students’ ability to perform correct laboratory experiment activity. Various studies showed V-labs have significant positive effects on students’ laboratory skills compared to traditional laboratory [14,17-20]. V-labs have positive effects if supported with proper textbooks and equipment [21]. That is, combining the V-labs with other learning media.

Improving students’ cognitive and conceptual understanding are important. But the students’ affective and psychomotor should not be marginalized. The V-labs gave positive effects on students’ learning motivation [11]. They found 78% of the students were interested to learn about the genetic with V-lab. Students’ conceptual understanding, confidence, and motivation have also improved due to the usage of V-Lab in microbiology. If viewed from conceptual understanding, V-Labs can be used to substitute the conventional laboratories and improve students’ confidence and motivation [11]. V-Labs cannot substitute traditional laboratory to improve students’ motivation. It because some students were uninterested if cases or problems were presented in V-labs, and prefer to real life representations [4].
The review showed the trend was focused on the research to compare the technology-aided learning. For example, [22] have studied the comparison between hybrid lab (V-labs with the touch screen) and conventional laboratory. They found out the hybrid V-labs have gained 15% better compared to the conventional laboratory. Some studies have different outcomes. Face to face laboratories have a better environment for students’ interactions and collaborations compared to V-labs [1].

The review showed the V-labs can be used as the alternative learning media to improve students’ conceptual understanding and laboratory skills. The V-labs can be effective if: a) The materials and equipment for experiments were expensive, b) limited time windows, c) problematic students’ ethics (d) difficulties in results interpretation (e) need for sophisticated instruments, and (f) usages of dangerous substances [1,19].

4. Conclusion
V-Labs is possible as alternative learning media to improve students’ conceptual understanding and laboratory skills. V-Labs have both positive and negative effects on students’ conceptual understanding and laboratory skills reviewed from cognitive, affective, and psychomotor aspects. The V-labs were used if the topics were abstract, dynamic, hard to visualize, and comprised of complex relationships between elements. The interdisciplinary topics were rarely used by researchers in virtual laboratories.

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