Virtual lab as distance learning media to enhance student’s science process skill during the COVID-19 pandemic

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Abstract. The emergence of problems such as the COVID-19 pandemic that currently occurred interfere the implementation of teaching and learning activities in schools. Especially for science learning, it is not only about the content but also the processes to improve student’s skills, such as science process skills. Current technological advances make it possible to conduct distance learning using media such as virtual lab. This study aims to review the comparison of the effectiveness between virtual lab and traditional lab, the use of virtual lab on student’s science process skills, and the use of virtual lab as a medium of distance learning. This study uses a systematic literature review method with 22 selected articles. The results indicate that the use of virtual lab media has the same or even better effectiveness than traditional labs. The use of virtual lab enable to enhance student’s science process skills, especially in predicting and measuring. This is because the virtual lab media able to provide opportunities and flexibilities for students to conduct experiments by the level of ability and pace of learning each student, anytime and anywhere. Thus, the virtual lab media is feasible to be used as an alternative substitute method for distance learning

1. Introduction

Indonesia is currently facing the spread problem of the COVID-19 virus, which has been declared as pandemic and has become an international public health problem [1]. As a consequence of this problem, the Indonesian government released various appeals in order to reduce the spread of the virus, such as social and physical distancing [2], with various taglines like work from home and study from home. This appeal directly impacts teaching and learning activities in schools. Especially science learning, where the essence of science is not only about content but also process [3], and laboratory activities in science learning play an important role in supporting the learning process [4]. Therefore, in the midst of conditions that make teaching and learning activities difficult to hold in schools, distance learning can be a viable and appropriate solution to ensure the sustainability of learning [5].

Distance learning (DL) is an emerging paradigm where students, teachers, and equipment may be at different geographic locations [6]. DL is an excellent method of teaching learners, because it has high flexibility to control the time, place and way of learning [7]. But this method also has weaknesses such as loss of motivation and science process skills of students, especially if this distance learning is only done by giving lab assignments [7,8]. By following the development of technology and the internet, DL can be implemented using virtual systems, such as virtual laboratories, to overcome the weaknesses of DL [8,9].
Virtual laboratory (VL) is a laboratory that carried out using computer software with real laboratory-look like equipment [10]. VL can be used to replace traditional laboratory (TL), especially for experiment that require an expensive, unsafe and unavailable equipment in lab [11]. This VL has characteristics such as low cost, high efficiency, good availability, easy sharing of resources, safe use and ease of operation [12], and students able to do an experiment repeatedly, so they can get more accurate and precise experiment result for helping them deeply understand the concept [11]. Besides VL, media that can be used is remote laboratory (RL). RL, by definition, is an experiment which located physically away from students, hence the experiment is conducted and controlled remotely via the network [11,13]. However, RL is still relatively new and requires more advanced equipment which is more expensive [14], so that it is difficult to apply in learning yet, especially in Indonesia [15]. Therefore, VL is an optimum method that is able to overcome problems in accessing laboratories and replace the role of TL in implementing distance learning (DL) in Indonesia [12,16,17]. VL is able to strengthen problem solving skills, critical thinking, creativity, conceptual understanding, motivation, perceptual interest, learning outcomes and especially students' science process skills (SPS) [18]. SPS define as a set of skills that are broadly applicable, appropriate to many science disciplines and reflective of the behavior of scientist [19]. SPS include observing, inferring, measuring, communicating, classifying, and predicting [19,20]. SPS needs to be trained and developed in the learning process [21], because by training SPS, students will be able to find their own concepts through experiments so that they are easier to understand and remember over a longer period of time [22].

Therefore, previous researchs on VL needs to be reviewed for finding out the feasibility of this VL, if it used as a DL medium to enhance students' SPS during the COVID-19 pandemic. This research is a literature review which aims to compare the effectiveness between VL and TL, the effect of using VL on student’s SPS, and the use of VL as DL media. Through this research, researchers wanted to find out the feasibility of using VL as a DL media to overcome the difficulty of procuring teaching and learning activities in schools due to the COVID-19 pandemic.

2. Method
This literature review used systematic review approach by Khan, et al. [23] which consists of 5 steps. The first step was framing questions for reviewing this topic. Three questions determined for this study were: (1) is there any comparison of the effectiveness between VL and TL?, (2) is VL effectively used to enhance student’s SPS, and (3) is VL feasible used as a DL media?.

The second step was identifying relevant work. This step focused on determining the database sources, the keywords search, the inclusion and exclusion criteria for the research articles. Articles reviewed were obtained from four database sources: ScienceDirect, ERIC, IEEE and Google Scholar. The keywords were used: virtual lab, traditional lab/real lab, science process skills and distance learning. Boolean Search terms (AND, OR) were used in order to limit our searches. The search was restriced to a date range of 2011-present. Search results were set to include national and international article in journal and conference proceedings. Search results were focused on empirical literature for the first and second research question. While for the third research question, intructional articles focused on design, software and hardware development or feasibility were also included. Search results were set to research in science and engineering education. There were 22 articles selected consisting of 7 articles for the first question (initially 13), 8 articles for the second question (initially 15), and 7 articles for the third question (initially 17).

The third step was assesing the quality of studies. The quality of the selected articles were assessed by expert to find out their eligibility. the 22 selected article were eligible to be reviewed. The fourth step was summarizing the evidence. This step consisted of presenting, exploring and analyzing data about comparison between VL and TL, effectiveness of using VL on student’s SPS, and the feasibility of using VL as DL media. The last step was reviewing the 22 selected articles and interpreting the findings.
3. Results and Discussion

The selected papers reviewed for each discussion are presented in table 1, 2 and 3. The tables consist of information about journal identity and summary.

| Title                                                                 | Author                          | Year | Summary                                                                                                                                 |
|----------------------------------------------------------------------|---------------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------|
| Virtual and Physical Experimentation in Inquiry-Based Science Labs: Attitudes, Performance and Access | Pyatt, K. & Sims, R.             | 2011 | The study result indicated that student performance on both VL and TL experiences were equally well.                                     |
| Virtual laboratory vs. traditional laboratory: which is more effective for teaching electrochemistry? | Hawkins, I. & Phelps, A. M.     | 2013 | The result showed that there were no significant difference between using VL or TL at teaching concepts and voltaic cell set-up in electrochemistry |
| Are Virtual Labs as Effective as Hands-on Labs for Undergraduate Physics? A Comparative Study at Two Major Universities | Darrah, M., et al.              | 2014 | There were no significant difference in learning outcomes between the use of VL, TL and VL-TL in 2 universities, which means the use of VL as effective as TL |
| Comparing Physical, Virtual, and Hybrid Flipped Labs for General Education Biology | Son, J. Y., et al.              | 2016 | The VL-TL method showed higher scores and more positive attitude towards biology than using the VL and TL methods independently.     |
| Peranan Praktikum Riil dan Praktikum Virtual dalam Membangun Kreativitas Siswa | Widodo, A., et al.              | 2016 | The results of the N-Gain analysis of the two practicums indicate that the use of TL has the potential to increase students’ creative thinking skills in all aspects compared to the use of VL. |
| Pengaruh Real Laboratory Dan Virtual Laboratory Terhadap Pemahaman Konsep Peserta Didik Dengan Kemampuan Awal Berbeda Pada Materi Kesetimbangan Kimia | Rohmah, M., et al.              | 2019 | This study showed that students who have low prior knowledge has higher conceptual understanding when taught using VL than TL.          |
| Using Hands-On and Virtual Laboratories Alone or Together – Which Works Better for Acquiring Knowledge and Skill? | Kapici, H. O., et al.           | 2019 | The use of the VL-TL combination in learning showed significantly better learning outcomes than the use of VL and TL methods independently |
### Table 2. List of articles on the effectiveness of virtual lab on students’ science process skills.

| Title                                                                 | Author(s)                  | Year | Summary                                                                                                                                 |
|----------------------------------------------------------------------|----------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------|
| Pengembangan Laboratorium Virtual Berbasis Algodoo Untuk Melatihkan Keterampilan Proses Sains Siswa Pada Pokok Bahasan Gerak Parabola | Luki, N. & Kustijono, R.   | 2017 | The use of VL has been proven to be effective in training student’s SPS to very good category.                                      |
| Training Science Process Skills Using Virtual Laboratory On Learning Acid, Base, And Salt | Lutfi, A. & Hidayah, R.    | 2017 | Learning activities using VL can train student’s SPS which is shown by the existence of student activities, completeness of learning outcomes, and positive student responses. |
| An Effective of POGIL with Virtual Laboratory in Improving Science Process Skills and Attitudes: Simple Harmonic Motion Concept | Alatas, F. & Fachrunisa, Z. | 2018 | The use of POGIL with VL has a positive impact on student’s SPS in all its aspects.                                                   |
| Scientific Approach-Integrated Virtual Simulation: A Physics Learning Design to Enhance Student’s Science Process Skills (SPS) | Siswanto, et al.           | 2018 | Learning activities using the scientific approach integrated with VL can significantly strengthen student’s SPS.                      |
| The Effectiveness Of Virtual Lab Compared To Physical Lab In The Mastery Of Science Process Skills For Chemistry Experiment | Ratamun, M. M. & Osman, K. | 2018 | The use of VL does not show significant effectiveness when compared to the use of TL in controlling SPS.                           |
| Peningkatan Keterampilan Proses Sains dan Pemahaman Konsep melalui Model Learning Cycle 5E Berbantuan Virtual Lab pada Materi Usaha dan Energi | Yulasti, N. I. et al.      | 2018 | Learning Cylce 5E model using VL can improve learning activities, SPS, and conceptual understanding of work and energy subject matter.|
| The Effectiveness of Students’ Worksheet of Virtual Laboratory Practice on Dynamic Electricity to Improve Science Process Skill | Zulimah, et al.            | 2018 | The use of VL assisted by students’ worksheet was very effective in learning to enhance students’ SPS.                             |
| Guided Inquiry Model Through Virtual Laboratory To Enhance Students’ Science Process Skills On Heat Concept | Gunawan, et al.            | 2019 | Guided inquiry learning model assisted by VL was significantly effective to improve students’ SPS.                                 |
| Title                                                                 | Author                | Year | Summary                                                                                                                                 |
|----------------------------------------------------------------------|-----------------------|------|------------------------------------------------------------------------------------------------------------------------------------------|
| Evaluating Usability in a Distance Digital Systems Laboratory Class  | Kostaras, N., et al.  | 2011 | VL as a DL medium requires accurate design, proper trial and formal evaluation before large-scale arrangements for students, in order to find out errors in use and ensure quality education |
| Assessing the Feasibility of Using Virtual Environments in Distance Education | Johnson, C. M., et al. | 2011 | The use of virtual-based media is the right choice in implementing DL, because it can create a clearer, more interesting and active discussion environment for students. |
| Challenges of Applying Online Learning Tools in Distance Learning Courses | Sancristobal, E., et al. | 2012 | Online learning media has been widely used in DL, such as VL which has advantages in accessing process, tracking student progress, and enabling students to work collaboratively. |
| The objectives, architectures and effects of distance learning laboratories for industrial engineering education | Stefanovic, M.        | 2013 | The concept of laboratories for DL using VL with different simulations have an important role in industrial engineering education and training. |
| A Web-based virtual laboratory for distance education                | Li, H                 | 2015 | Web-based VL as DL medium has the potential to be widely applied in science education and be a major trend in developing experimental methods for DL. |
| Development of Virtual Laboratory Application Structure in Android Cellphone for Distance Learning | Zheng, W., et al.     | 2017 | The VL atmosphere can give students the flexibility to carry out various experiments for DL. |
| Adapting RealTime Physics for Distance Learning with the IOLab       | Bodegom, E., et al.   | 2019 | Introductory experiments in physics laboratories can be effectively presented on DL by using VL, in this case IOLab, at low cost. |

3.1. Virtual lab VS traditional lab

Along with the development of technology and the emergence of various online schools or campuses, VL has experienced rapid growth [24]. This is because laboratory activities have a very important role in providing practical experiences for students as a center for learning concepts and include an active participation of students which is useful for improving memory in learning [10,25]. In line with the research results of Georgiou et al. [26] who show that humans only remember 10% of what is read, 20% of what is heard, but retains 90% of what is learned through active participation. The use of VL is not only limited as an introductory medium for laboratory introductions, but is also used as additional media or substitute media for the implementation of TL [24,25]. VL has several clear advantages as mentioned
by Bhargava et al. [27] & Darrah et al. [25]: reducing the need for equipment, available anytime and anywhere, offering students more information, and allowing students to learn and work on more difficult concepts at their pace.

The use of VL is still doubted as a substitute medium for TL, due to philosophical reasons or concerns about the poor implementation of VL in teaching concepts and techniques of the practicum [24]. But in fact, the use of VL in learning is equally or more effective than the use of TL in conveying and understanding concepts [24,25], improving process skills and learning outcomes [10], as well as a positive attitude [28]. This is also supported by the results of a research study conducted by Brinson [29], where the use of VL in learning is equally or even better than the use of TL in increasing the achievement of learning outcomes, which include knowledge and understanding, inquiry skills, practical skills, perception, analytical skills, and socio-scientific communication. Student’s active participation also increases when using VL, this is because students feel interested in learning to use VL [10]. Students consider the experience of using VL to be realistic, authentic, challenging and more thorough [30]. Analysis of creative thinking skills researched by Widodo, et al. [31] turned out to show different results, because the use of TL provides more optimal conditions for training creative thinking skills than the use of VL.

The difference in the students’ initial abilities did not have a significant effect on the differences in students’ conceptual understandings using VL, TL or mixed [32,33]. However, students with low initial abilities have a higher conceptual understandings when taught using VL than TL [33]. This is because VL provides flexibility to students in doing practicum anytime, anywhere and according to their respective abilities and needs [26,27]. The use of VL provides more flexibility for students to focus on achieving learning goals, solving problems, analyzing and interpreting data, and its use is easier and works better than TL [30].

The implementation of VL, both in schools and universities, is considered important as a simulation or introduction medium, additional medium, as well as a substitute medium for TL to overcome problems and limitations in fulfilling the needs and increasing the number of laboratory participants [10,25,28]. Large-scale implementation of VL requires the support of other methods to achieve better results, such as combining it with group discussion activities or expert explanation sessions [24,28]. The implementation of VL must pay attention to the grade levels, learning perceptions from students, and preferences for desired learning outcomes to be achieved [28,29]. The use of VL is also very suitable as an additional medium for TL, where the combination of VL-TL shows better results than used alone [28,34].

3.2. The effectiveness of virtual lab on students’ science process skills

Generally, students’ SPS refer to the skills that students have such as scientist who carry out the scientific research process or it can be interpreted as behavior that encourages skills to acquire knowledge [3]. Mastery of SPS will only be achieved if the teacher is able to consider the appropriate type of laboratory to be used in teaching certain materials [35], such as the use of VL media [3][36-39]. The use of VL media is able to train students’ SPS to a very good category [36,39]. This is because VL is able to make students more enthusiastic and prepare students to conduct experiments independently with guidance by the teacher [3,38]. The teacher also has an important role as a motivator or guide to facilitate the use of VL media [38].

The aspect of students’ SPS that is most influenced by VL is the predicting aspect [36,39,40] and measuring/practicing [3,37]. This is because VL media is able to help students focus, urge student to be creative, lead students to find concepts independently [36], and train students to predict and analyze these concepts [40]. Communicating [36,39] and inferring/hypothesizing [38,40] are aspects that are not significantly affected by the use of VL. This is due to the lack of specific activities that students need to do in this aspect [40]. The use of student’s worksheets can be a solution in helping the implementation of VL to be more effectively and specifically in improving all aspects of students’ SPS [39].

The use of VL media still has lower effectiveness than TL in improving students’ SPS [35]. Meanwhile, the use of VL is able to improve student KPS at each meeting [35,38], which means that
the use of VL can still be better. This is because the VL media is able to increase student activity [37,38]. Therefore, VL can be the right option for teachers in guiding students to conduct experiments in more systematic way [35]. VL is a medium that is very flexible to be used and combined with various other learning methods such as guided inquiry model [3], and 5E learning cycle model [38], scientific approach [40] and the Process-Oriented, Guided-Inquiry Learning (POGIL) approach [41].

3.3. Virtual lab as distance learning media

Students in DL are scattered in several locations which makes it difficult to hold face-to-face learning, and most DL is conducted with limited interactions which is not attracting student participation [42,43]. VL is the best medium for maintaining active learning that supports the optimization of DL [42], because VL has the advantage of being accessed anytime and anywhere, creating an attractive discussion environment for students, expanding the scope of teaching and experimentation, tracking progress students with a “log files” system, and allowing students to work collaboratively with various other online media or web [12,26,27,42,43]. In addition, VL also provides opportunities and flexibilities for students to carry out various experiments and act collaboratively which helps students to understand concepts [44–46]. Therefore, VL as a DL learning media has the potential to be widely applied in the fields of education and science and is a major trend in developing experimental methods for DL [12].

The results show that learning using VL gives students a sense of presence like in a real environment, so it can enhance the learning environment and perception of the quality of the content delivered, even though they are in different locations and environment [42]. In addition, students show great conceptual understandings and positive perceptions when using VL in DL compared to using TL [47]. However, DL using VL leaves several questions and problems for students, therefore communication between teacher (instructor) and students is needed to solve the problems faced through the experiment for the smooth learning of DL using VL [44,47].

The setting up of VL in DL requires careful design, pilot runs, formal evaluation [44], realistic problem themed experiments, specific learning objectives, self-paced learning tool, a large amount of additional material and other web links [45], and understanding of its benefits and limitations so that can be developed into more optimal educational environments [42]. The experiments contained in the VL also need attention. Experiments that illustrate the phenomenon are more suitable to be applied to DL than experiments that require additional skills, so it is necessary to know which experimental objectives are good for doing through VL and TL [45].

4. Conclusion

Based on the results of the literature review conducted, it can be concluded that: (1) The use of VL media has the same or even better effectiveness than TL; (2) VL media is effectively used to enhance students’ SPS; (3) VL media is feasible to be used as a medium for DL. In addition, VL also shows several advantages such as easy access anytime and anywhere, less costs required and provides flexibility for students to conduct experiments according to their respective ability levels and learning speeds.

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