



Science Virtual Laboratory Implementation to Improve Students' Critical Thinking Skills: A Content Analysis

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Abstract: Critical thinking skills are important for students to have for their future. One way to improve it is to apply virtual laboratory learning media to Science subjects. This study aims to analyze the implementation of virtual labs to improve students' critical thinking skills in science learning. This qualitative descriptive research uses content analysis study method. Researchers collect and classify various research results on the application of Virtual Laboratory (VL) from the S1-S3 Journal of Sinta using the PRISMA method and analyze them using a research instrument in the form of a Paper Classification Form (PCF). As a result, research on the use of virtual laboratories to improve students' critical thinking skills in science learning continues to increase from year to year, from high school to university levels. PhET and virtual labs developed by researchers when applied in class using inquiry models or STEM approaches or experimental methods have been proven to be able to effectively stimulate students to think critically.

Keywords: Critical thinking skills; Science learning; Virtual laboratory

Introduction

Science can be called a systematic knowledge that is studied and obtained through a process of observation, research, and experimentation. Science has dimensions: scientific attitudes, processes, products, and applications, thus providing learning experiences to understand how the universe works through an empirical approach. Keputusan Kepala Badan Standar, Kurikulum, dan Asesmen Pendidikan (BSKAP) Kemendikbudristek Indonesia number 8 of 2022 concerning learning outcomes explains the objectives of learning science in the Independent Curriculum. These objectives include developing students' curiosity about the study of scientific phenomena around them, making students play an active role in protecting the environment, developing students' inquiry process skills, and developing knowledge and understanding of science concepts in everyday life. Students are trained to be able to find facts and build concepts that are studied holistically, authentically, and meaningfully so that student can have 21st century skills.

In this century, there are Industrial Revolution 4.0 and Society 5.0 which affects all aspects of life including the fields of technology, economy, transportation, communication, information, etc. Thus, students need 21st century skills, namely important skills that must be mastered, so they will be able to face challenges, problems, life, and careers in the 21st century (Erdoğan, 2019; Redhana, 2019). Critical thinking skills is one of several 21st century skills besides problem solving skills, communication skills, ICT literacy, information literacy, and media literacy (Prihadi, 2018). The high-level cognitive domains targeted by critical thinking skills are analyzing (C4), evaluating (C5) and making (C6).

Critical thinking skills can help students think logically to solve problems, see problems from various perspectives, be creative in finding ideas, and be rational in making decisions. In short, critical thinking needs to be owned by today's students. However, the fact is that the critical thinking skills of Indonesian students are still low. Based on the survey results of The Trends in International Mathematics and Science Study (TIMSS), improving the ability of Mathematics and Science subjects for Grade IV and VIII students is still a cause for

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concern. In 2007, Indonesia ranked 36th out of 49 countries in 2007. In 2011, Indonesia ranked 32nd out of 49 countries, while in 2015 the results of the 2015 TIMSS study Indonesia fell to 46th place out of 51 countries with an average score of 397 (Retnowati & Ekayanti, 2020). Currently, there is no TIMSS survey ranking for Indonesia because Indonesia did not participate in the study in 2019 (Mullis et al., 2020). Based on these data, the cognitive domain (reasoning, application and knowledge) and the content domain (algebra, geometry, numbers, data and probability) of Indonesian students have decreased. Thus, it can be seen that the level of critical thinking skills as part of the cognitive domain of students in Indonesia needs further attention.

To be able to solve the problem, we need to know the root cause. The low ability to think critically is caused by the models, methods, and learning media used by the teacher. Learning in class tends to be one-way dominated by the teacher so that students only hear and memorize material (Hairida & Hadi, 2017). Sometimes, the learning method chosen by the teacher is less attractive to students, less interesting, or less varied, so the atmosphere in the class is less interactive and not conducive (Ramdiah et al., 2014). Especially during the Covid-19 pandemic, learning was forced to take place online so that many students experienced learning loss (Rengkuan et al., 2022) or academic setbacks due to prolonged gaps or the educational process not taking place. Research conducted by Pratiwi (2021) revealed that during the pandemic several problems occurred, namely 1) student motivation and psychological learning decreased; 2) gaps in learning outcomes arise due to differences in background and facility support; and 3) learning loss happens. So, a solution is needed so that learning can be interactive again and improve students' critical thinking skills.

Virtual laboratory or simulations of laboratory practicum using gadgets can support students to interactively explore and visualize abstract concepts, especially in describing the application of knowledge (Başer & Durmuş, 2010) and learner's learning motivation. Virtual laboratory can provide macroscopic visualization for both abstract and concrete material, facilitate students to conduct experiments with radioactive or hazardous materials safely and cost-effectively (Herga et al., 2014). Apart from being able to facilitate virtual experiments during the Covid-19 pandemic, virtual labs can also be an alternative for schools that lack practicum tools or lack qualified facilities.

With the growth of the trend of using virtual labs in science learning, researchers are interested in analyzing how they influence students' critical thinking skills.

Method

This descriptive qualitative research uses content analysis study method. Researchers collect and classify various research results on the application of Virtual Laboratory (VL) based on certain aspects using a research instrument in the form of a Paper Classification Form adapted from (Kizilaslan et al., 2012). PCF is composed of seven sections of seven sections namely descriptive information on papers, fields of study, subject matter, research design/methods, data collection tools, grouping samples into ten groups, and data analysis methods/techniques used in the research.

The articles analyzed were collected from the S1-S3 Journal of Sinta using the PRISMA method. Identification of research articles from the database includes steps: identification, screening based on inclusion and exclusion criteria, and eligibility assessment (Page et al., 2021). Based on records identified from through database searching, there are 2236 articles found after searching "Virtual AND Lab" and "PhET OR Simulation" on Google Scholar document searching in Sinta. Furthermore, the inclusion criteria were applied in the screening, including 1) articles in S1-S3 journals, 2) year between 2012-2022, 3) open access articles, and 4) research settings in Indonesia. After obtaining 152 articles as the screening results, then the eligibility of each article is checked whether it is relevant to the study or not. As a result, 18 articles were obtained for content analysis. This research is limited to the application of VL to improve students' critical thinking skills in science learning.

The researcher determines several criteria taken in the study content analysis, including the VL type used, year of publication of the article, research sample, and research method, science material integrated with virtual laboratory, data collection instruments, and benefits of using virtual laboratory in Science learning.

Result and Discussion

Virtual laboratory is an innovative learning media that utilizes electronic devices for its operation. Virtual laboratory is defined as a form of complex interactive multimedia object (Gunawan & Liliyasi, 2012). There are many types of virtual laboratories, but the one most widely used based on the results of this analysis is PhET. Software in the form of Physics Education Technology (PhET) developed by the University of Colorado is a site that provides learning simulations for physics, chemistry, biology, earth science, and mathematics. Virtual PhET laboratory can make students understand concrete or abstract materials easily (Zulkifli et al., 2022) because it facilitates students to explore various science concepts with pictures, animations, and interactive labs. PhET is easily accessible in the classroom because it can be downloaded to be accessed offline or run directly online.

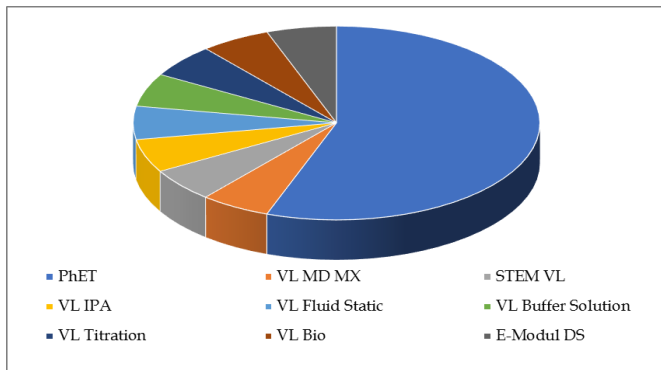


Figure 1. Types of virtual laboratory implemented in science learning

Based on the analysis of the contents of the journal, PhET is effectively used in learning Science (Febrianto et al., 2021; Harum et al., 2020; Malahayati & Saminan, 2016; Musdar et al., 2015; Najib et al., 2013; Rahmadita et al., 2021; Rohmah & Prahani, 2021; Verawati & Hikmawati, 2021; Yulianti et al., 2021; Zahara et al., 2015). There are also various virtual laboratories developed by the author, including Virtual Lab based on Macromedia Director MX (Gunawan & Liliarsari, 2012), STEM based Virtual-Lab (Sari et al., 2022), Virtual Lab IPA (Lestari & Herianto, 2022), Virtual Fluid Static Laboratory Based on Macromedia Flash (Kurniawan et al., 2018), Virtual Lab of Buffer Solution (Arfa et al., 2020), Virtual Lab of Acid Base Titration (Sari et al., 2020), Virtual Biology Laboratory (Aripin & Suryaningsih, 2020), and E-Modul Dygestive System with Virtual Lab (Ravista et al., 2021) or can be seen in Figure 1.

Through a virtual laboratory, students can conduct experiments by manipulating independent variables to obtain data on the dependent variable and then interpreting it in learning. Just like PhET, the working principle of the virtual lab is just the same. However, some virtual labs are not widely published so that they are only used in limited classes.

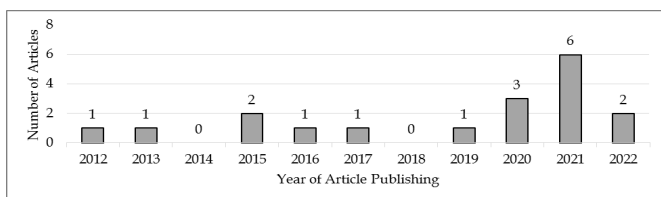


Figure 2. Number of virtual lab articles in Indonesia in the 2012-2022 interval

In Figure 2, we can observe the distribution of years of research. Currently, the VL research trend is increasing, and the number is very large. The number of VL research on science learning in Indonesia in the period 2012-2022 totaled 16 articles. Few articles were

analyzed because they were limited to S1-S3 Sinta Journals.

The highest increase in VL research occurred in 2021. During this period, the whole world was being hit by the Covid-19 pandemic, so all learning was carried out online. Therefore, the trend of online or virtual research has increased sharply, especially in Science learning.

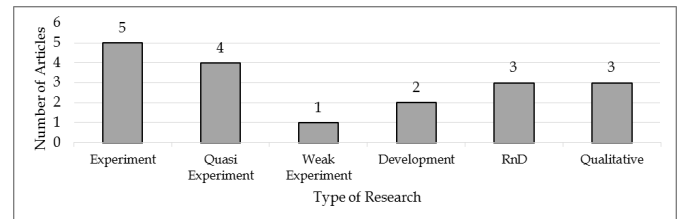


Figure 3. Virtual laboratory research methods

Virtual Lab research methods on science learning are quite varied. This research is devoted to analyzing the implementation of a virtual laboratory to improve students' critical thinking skills so that most of the research analyzed uses the experimental method. Of the articles that applied the experimental method, some of the experimental types were not explained, four researchers used quasi experiments, and some even used weak experiments. Fraenkel and Wallen's weak experiment is a method that is not widely used because it does not have a control group, so the increase in the measured independent variables is less visible. Educational research always has outside research variables that cannot be controlled, in contrast to pure science whose variables can really be controlled. So, the usual quasi-experimental method is recommended if you want to do experimental research. Experimental research designs mostly use pretest posttest control group design because it makes it easier for researchers to analyze the effect of treatment. There are four virtual lab development research analyzed. At there, researchers develop new or modified Virtual Labs for science learning. There are two qualitative research, which include descriptive research and qualitative studies.

Research related to the application of virtual labs in science learning to improve critical thinking skills has mostly been carried out by middle school to university students according to Figure 4.

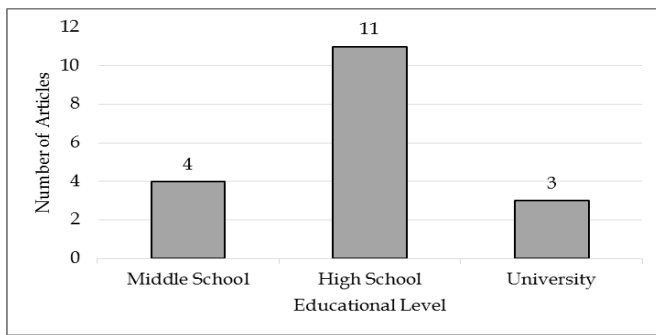


Figure 4. The distribution of educational levels

Virtual laboratory is just a learning media. Its existence cannot improve critical thinking skills without appropriate learning methods. So, it is important for researchers to choose learning methods that are recommended by researchers so that their research can be effective and efficient. Table 1 below shows the model or approach or learning method applied to science subjects in the journals analyzed.

Table 1. Learning Models or Approaches or Methods Applied to Science Subjects

Science Material	Learning Models/Approaches/Methods
Bacterial	Biology, Technology, Engineering, and Mathematics (BTEM) Approach
Photosynthesis	Constructivism Approach
Digestive System	Guided Inquiry Model
Environmental Pollution	Experimental Method
Buffer Solution	Guided Inquiry Model
Acid Base Titration	Predict-Observe-Explain Model
Fundamental Unit	STEM approach
Static Fluids	Guided Inquiry Model Experimental Method
Electrical circuits	Problem-Based Learning Model Inquiry Model
Light	Free Inquiry Model
Vibration and Waves	Guided Inquiry Model Generative Learning Model
Modern Physics	Interactive Simulation Method
Not mentioned	Problem-Based Learning Model

Based on Table 1, the dominant models or approaches or learning methods are inquiry models, STEM integrated approaches, and simulation or experimental methods. The experimental method is natural if it is dominant because activities in the virtual laboratory cannot be separated from experimentation. The STEM approach is used because Virtual lab can present science, technology, engineering, and mathematics (STEM) to students through interesting activities (Sari et al., 2022). The inquiry model is widely used because it facilitates students to be active in discovering concepts independently or in groups or guided by a teacher (Arfa et al., 2020; Ulfa et al., 2022). This model includes syntax: orientation, formulating problems, formulating hypotheses, defining, exploring, and proving that can stimulate students to think at a

higher level. Thus, many researchers use this model as a bridge to the application of virtual laboratories to achieve increased students' critical thinking skills in Science learning.

In each study, data collection uses certain instruments. Based on the results of the analysis, the test instruments used generally include tests in the form of questions, observation sheets, questionnaires. The three instruments need to be validated before being used. There is also a qualitative research that uses interview and questionnaire techniques, so it requires instruments in the form of interview question sheets and questionnaire sheets. In essence, the instruments used by researchers adjust data collection techniques and research needs.

After being applied in learning, all research leads to the conclusion that the application of a virtual laboratory can facilitate students to find their own concepts, so that their critical thinking skills increase. The proof is, in almost all studies, the N-gain and effect sizes obtained show that there is an increase in students' critical thinking skills after learning with a virtual laboratory.

Conclusion

Based on the studies that have been conducted by researchers, it can be concluded that research on the use of virtual laboratories to improve students' critical thinking skills in science learning continues to increase from year to year, from high school to university levels. PhET and virtual labs developed by researchers when applied in class using inquiry models or STEM approaches or experimental methods have been proven to be able to effectively stimulate students to think critically.

Author Contributions

The lead author, Risa Nurullailiyah Sujono, contributed to building ideas, conducting research, and exploring data analysis. The second and third authors, Jumadi Jumadi and Maryati Maryati contributed to guiding the research and writing of this article. All authors have approved the final published manuscript.

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Conflict of Interest

In this study, there is no conflict of interest.

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