



# Comparative Analysis of Students' Science Process Skills Using Virtual Laboratory in Photoelectric Effect Experiments

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**Abstract:** The use of virtual laboratories in distance learning has increasingly developed as a solution to overcome the limitations of physical laboratory access, particularly in fostering students' science process skills. This study aims to analyze students' science process skills in a photoelectric effect experiment using two virtual laboratories: PhET Simulation and Amrita VLab. The research method employed is quantitative descriptive analysis, Microsoft Excel (the analysis Toolpak, Pivot table, and Pivot chart), involving physics education students as respondents. Data were collected through an assessment of science process skills based on 13 indicators and the effectiveness of the virtual laboratories across 8 aspects, which were then analyzed using descriptive statistics. The results indicate that observation skills scored the highest (91.56%), while analytical skills received the lowest score (71.56%). In terms of effectiveness, PhET Simulation excelled in supporting conceptual understanding, while Amrita VLab provided a more realistic experimental experience. These findings suggest that virtual laboratories are effective in enhancing students' science process skills in different contexts, depending on the learning objectives.

**Abstrak:** Penggunaan laboratorium virtual dalam pembelajaran jarak jauh semakin berkembang sebagai solusi untuk mengatasi keterbatasan akses laboratorium fisik, terutama dalam mengembangkan keterampilan proses sains mahasiswa. Penelitian ini bertujuan untuk menganalisis keterampilan proses sains mahasiswa dalam percobaan efek fotolistrik dengan menggunakan dua laboratorium virtual, yaitu PhET Simulation dan Amrita VLab. Metode penelitian yang digunakan adalah analisis deskriptif kuantitatif menggunakan Microsoft Excel (analisis Toolpak, tabel/grafik Pivot) dengan melibatkan mahasiswa pendidikan fisika sebagai responden. Data diperoleh melalui penilaian keterampilan proses sains berdasarkan 13 indikator dan efektivitas laboratorium virtual dari 8 aspek, yang kemudian dianalisis menggunakan statistik deskriptif. Hasil penelitian menunjukkan bahwa keterampilan observasi memiliki skor tertinggi (91,56%), dan keterampilan analisis mendapat skor terendah (71,56%). Sedangkan dari segi efektivitas, PhET Simulation unggul dalam mendukung pemahaman konsep dan Amrita VLab unggul dalam memberikan pengalaman eksperimen yang realistis. Hasil ini mengindikasikan bahwa laboratorium virtual efektif meningkatkan keterampilan proses sains mahasiswa dalam konteks yang berbeda, tergantung pada tujuan pembelajaran.

## INTRODUCTION

Science education has an important role in preparing students to think critically and conduct scientific research. One of the important aspects of science education is the mastery of Science Process Skills,

which includes 1) basic skills: observation, calculation (hypothesis), and measurement (experimental design), 2) integrated skills: compiling data tables, obtaining and processing data, conducting experiments, and inferring (Darmaji et al.,

2019). Science process skills help students not only understand theory but also engage in scientific practices more deeply (Sari et al., 2020). However, with the advent of distance learning and technology-based learning, the development of science process skills through physical laboratories has become a challenge in itself (Setiono & Astuti, 2021). This is what drives the development of the Virtual Laboratory in conducting physics experiment simulations without space and time limitations.

Virtual Labs have become an innovative tool in science education, especially in the context of distance learning (Potkonjak et al., 2016). According to Davenport (2018) research, the use of virtual laboratories in learning is able to provide learning outcomes comparable to physical laboratories, especially in developing analytical skills (Davenport et al., 2018). In addition, the flexibility of the virtual laboratory allows students to repeat experiments, control variables, and access a variety of simulations, which supports the development of science process skills in a learning environment (Daineko et al., 2017). According to Hamed & Aljanazrah (2020), virtual simulations in science education not only help students understand abstract concepts, but also allow them to conduct experiments that would be risky or expensive if done in a physical laboratory (Hamed & Aljanazrah, 2020).

Amrita Virtual Laboratory (Amrita VLab.) is a virtual laboratory platform developed by Amrita Vishwa Vidyapeetham, a research university in India. Amrita VLab is designed to provide students and researchers with virtual science and engineering practicum and experiment experiences (Patange et al., 2022). Amrita VLab reflects the evolution in the approach to practicum learning by utilizing digital technology (Nedungadi et al., 2018). PhET Interactive Simulations is

a web-based learning platform developed by the University of Colorado Boulder, PhET provides a learning experience that supports a constructivist approach, where students can explore abstract concepts in physics, chemistry, biology, and mathematics through intuitive and visual simulations (Saudelli et al., 2021). As of 2024, PhET has been widely adopted in various fields of education around the world to support active and interactive learning (Price et al., 2018).

The photoelectric effect was discovered by Albert Einstein, proving the interaction between light and matter, and providing strong support for quantum theory (Kapil, 2018). A deep understanding of the photoelectric effect requires good experimental skills, including observation of electron emission patterns and measurement of light intensity (Rablau et al., 2019). This experiment requires students to master good science process skills, which in conventional learning may be difficult to do without the help of complete laboratory equipment. The virtual laboratory offers a solution by allowing students to explore the phenomenon of the photoelectric effect visually and interactively (Ranjan, 2017).

This research is based on the theory of Constructivism put forward by Lev Vygotsky (1978), which emphasizes that effective learning occurs when students are actively involved in the learning process, especially through experimentation and reflection (Mohammed & Kinyo, 2020; Vygotsky & Cole, 1978). Through virtual labs, students can construct their understanding of physics concepts by trying out various experiments in a safe and flexible environment (Daineko et al., 2017; Hamed & Aljanazrah, 2020). In addition, Sweller's (2011) *Cognitive Load theory* states that visualization and interaction through simulation can reduce students' cognitive load in understanding abstract concepts, such as the photoelectric effect, thus allowing them to focus on

understanding and analyzing data (Sweller et al., 2011). The virtual laboratory allows students to run experiments with controlled variables and in-depth simulations without physical and material limitations (Potkonjak et al., 2016). It has become very relevant in physics education, where experiments such as the photoelectric effect require a deep understanding of concepts and a mastery of good science process skills (Payudi et al., 2017).

The latest of this study lies in the in-depth assessment of students' science process skills in the context of photoelectric effect experiments using virtual laboratories, as well as the evaluation of aspects of the effectiveness of virtual laboratories that have not been widely researched simultaneously. Previous research such as by Zacharia and Olympiou (2011) showed that virtual laboratories are effective in improving conceptual understanding and experimental skills, but do not provide a detailed analysis of individual science process skills (Zacharia & Olympiou, 2011). Another study conducted by Ali and Ullah (2022), which focused on the general effectiveness of virtual laboratories in science education, but did not analyze science process skills specifically (Ali et al., 2022). Research by Navarro (2024) shows that although virtual laboratories affect learning interests, their effects on specific skills such as analysis are still not clearly defined (Navarro et al., 2024). Therefore, this research fills the gap in the literature by providing a comprehensive evaluation of the influence of virtual laboratories on science process skills, as well as identifying aspects that require further development.

## RESEARCH METHOD

This research uses a quantitative descriptive method, Microsoft Excel (the analysis Toolpak, Pivot table, and Pivot chart), to analyze students' science process

skills in photoelectric effect experiments conducted in a virtual laboratory. The respondents were students of the physics and physics education study program. Data were collected through observation sheets and questionnaires, which assessed 13 indicators of science process skills divided into basic skills and integrated skills as presented in Table 1, as well as 8 aspects of virtual laboratory effectiveness, including material suitability, flexibility, and usefulness. This questionnaire is designed to evaluate how effective the virtual laboratory is in supporting learning as well as improving students' science process skills. The Virtual Laboratory used is PhET Simulation (Figure 1.) and Amrita VLab (Figure 2).

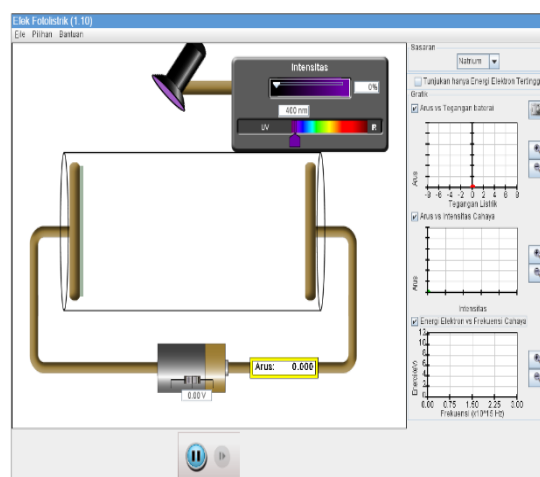


Figure 1. PhET Simulation

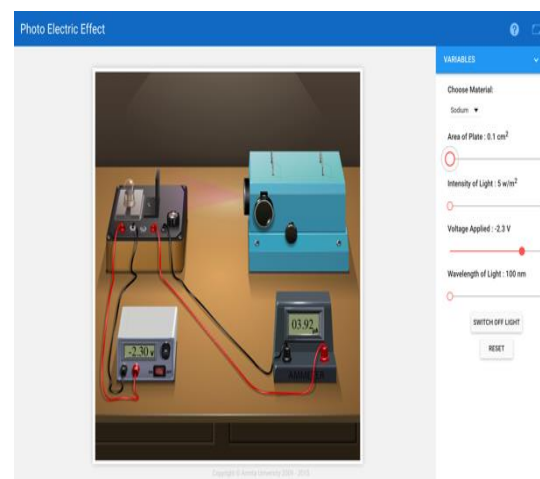


Figure 2. Amrita VLab

Data analysis was carried out using descriptive statistical techniques, where each indicator of science process skills and aspects of the virtual laboratory was calculated on average in the form of percentages. The results of this percentage are used to evaluate the extent to which students master science process skills through the use of virtual laboratories and to identify areas that require further development.

**Table 1.** Indicators of Science Process Skills Instruments

Science Process Skills	Indicators
Basic	Observation
	Classification
	Communication
	Measurement
	Conclusion
	Prediction
	Variable identification
Integrated	Data organization
	Relationship between variables
	Data processing
	Analysis
	Hypothesis Formulation
	Experimentation

(Chabalengula et al., 2012)

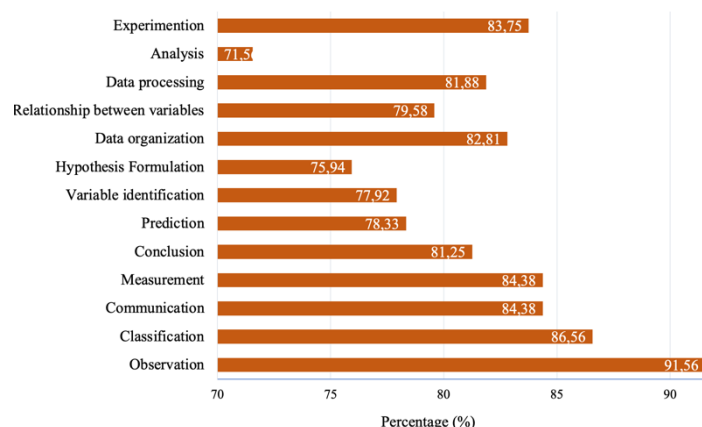
## RESULT AND DISCUSSION

### Results

The first figure presents the percentage of science process skills mastery based on 13 indicators, while the second figure illustrates the percentage of virtual laboratory effectiveness evaluated across 8 aspects.

#### 1. Science Process Skills Analysis

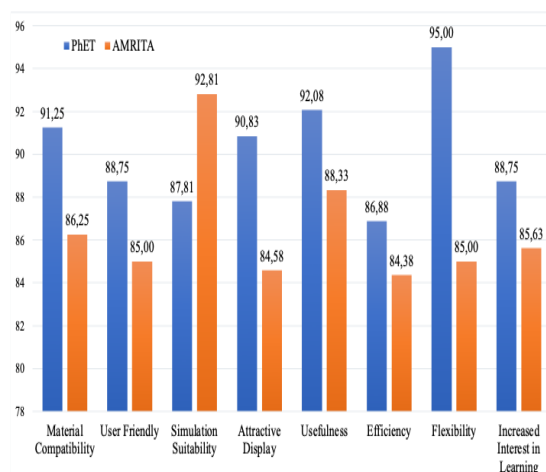
The results show that the students' science process skills in photoelectric effect experiments are generally at a high level, as presented in Figure 3. These results indicate that students have excellent observation skills. However, there are skills that still need to be improved, namely analytical skills.



**Figure 3.** Students' Science Process Skills

#### 2. Virtual Laboratory Effectiveness Analysis

The virtual laboratory used in this research is assessed from various aspects related to its effectiveness and ease of use by students, as presented in Figure 4. Both virtual laboratories are considered very good in terms of usefulness and flexibility. The attractive and *user-friendly* aspect of the display also received high appreciation, showing that this virtual laboratory is well designed to support learning.



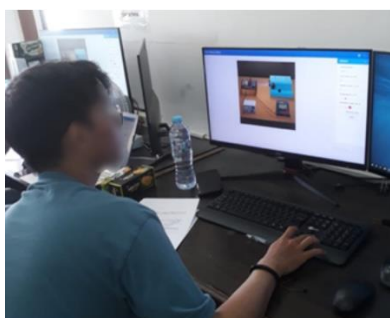
**Figure 4.** Comparison of PhET and Amrita VLab

### Discussion

This research has shown that the use of virtual laboratories in the classroom can significantly improve students' conceptual understanding and engagement, especially in distance learning (Ahmed & Hasegawa, 2019; Usman et al., 2021). The virtual lab

also facilitates science process skills by providing opportunities for students to conduct virtual experiments independently (Artun et al., 2020).

From the perspective of science process skills (Figure 3), the research results indicate that observation skills received the highest score (91.56%). This suggests that the virtual laboratory successfully aided students in observing phenomena in a detailed and accurate manner. This aligns with the findings of Singer et al., as cited in Sari U. et al. (2017), which demonstrated that interactive simulations help students develop better observation skills compared to conventional teaching methods (without simulations) (Sari et al., 2017). Virtual laboratories enable students to focus on details that might be missed in physical experiments, such as the pattern of electron emission in the photoelectric effect experiment (Figure 5).



**Figure 5.** Observation Skills on The Phenomenon of Electron Emission Patterns

Classification and communication skills also received high percentages, at 86.56% and 84.38%, respectively. According to Firmayanto et al. (2021), virtual laboratory simulations enable students to categorize data more systematically because all variables can be clearly controlled and manipulated in the virtual environment. Communication skills also improved, as students were trained to describe and explain their experimental results in detail (Firmayanto et al., 2021).

This is relevant to the findings of Chiu (2015) and Kapici (2019), who state that although virtual laboratory simulations can enhance conceptual understanding, students often struggle with analyzing complex data without additional guidance (Chiu et al., 2015; Kapici et al., 2019). Therefore, developing more structured instructional materials for using virtual laboratories could help improve analysis skills. This research reinforces previous findings that virtual laboratories can enhance science process skills. Additionally, the use of virtual laboratories has shown similar results with significant improvements in observation and communication skills. However, challenges in developing analytical and experimental skills remain an issue that requires further attention.

The comparison between PhET Simulation and Amrita VLab in the learning of the photoelectric effect highlights the strengths and weaknesses of each platform. In terms of material compatibility, PhET Simulation received a higher (91.25%) compared to Amrita VLab (86.25%). This indicates that the material presented in PhET is more suitable for the learning needs of the photoelectric effect concept. The alignment of this concept is supported by simulations that depict the emission of electrons from metals when illuminated by light, incorporating various related variables. Previous research by Inayah et al. (2021) demonstrated that materials specifically designed for virtual simulations can accelerate the understanding of physics concepts, supporting these findings (Inayah & Masruroh, 2021). However, in terms of simulation suitability with real experiments, Amrita VLab outperformed PhET (92.81% compared to 87.81%), indicating that Amrita VLab is more realistic in depicting physics experiments. This includes stages such as assembling equipment and materials, along with

instructions tailored to the objectives of the experiment. These results align with the research by Höhner (2020), which showed that reality-based simulations are closer to real laboratory experiences (Höhner et al., 2020).

Next, in terms of user-friendly, PhET performed better (88.75%) than Amrita (85.00%), indicating that the interface and design of PhET are more accessible for students. This relates to the technology used by both platforms; Amrita still employs Adobe Flash, while PhET has transitioned to HTML5, offering several advantages such as cross-platform compatibility, enhanced security, long-term accessibility, and improved performance due to faster and more responsive interactions (Zhou, 2018). In terms of attractive display, PhET also excels with a value of 90.83%, compared to Amrita's 84.58%, reflecting that PhET's visual design is more engaging and interactive. Attractive visual presentation has been shown to be crucial in capturing students' attention and interest in learning content, as noted by (Ilana et al., 2021). Engaging visuals can significantly enhance the learning experience by making complex concepts more accessible and stimulating curiosity among students.

In terms of usefulness and efficiency, PhET is also better with a usefulness value of 92.08% and efficiency of 86.88%, compared to Amrita which recorded 88.33% usefulness and 84.38% efficiency. This advantage reflects that PhET can provide a more rewarding learning experience with more efficient time. The flexibility of using PhET was also higher (95.00%) than Amrita's (85.00%), which supports the findings of Putra (2021) regarding the importance of flexibility in learning simulations to enable wider experimentation (Putra et al., 2021). However, Amrita VLab still showed its strength in increasing interest in learning, even though it was slightly lower than

PhET, with a score of 85.63% compared to 88.75%.

Overall, PhET Simulation excels in terms of ease of use, attractive appearance, flexibility, and efficiency. Meanwhile, Amrita VLab excels in the compatibility of the simulation with the live experiment, which makes it more realistic and closer to the actual laboratory experience. This research supports the use of both platforms in different contexts, depending on the learning objectives, both to support conceptual understanding (PhET) and for realistic simulations (Amrita).

## CONCLUSION

Based on the results of the research, it can be concluded that the use of virtual laboratories, both PhET Simulation and Amrita VLab, can significantly improve students' science process skills. PhET Simulation excels in terms of ease of use, attractive appearance, flexibility, and efficiency, which makes it more suitable for supporting concept understanding and experimentation with a wider variety. Meanwhile, Amrita VLab shows superiority in the suitability of the simulation with live experiments, which is very close to the real conditions in the laboratory, thus making it more effective for providing realistic experimental experiences. As such, the choice of virtual laboratory platform should be tailored to the specific needs of the learning objectives.

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