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Exploring Students' Perceptions of Virtual and Physical Laboratory Activities and Usage in Secondary Schools

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Abstract. Laboratory experience has been indicated as a crucial component of science teaching for practical skills acquisition and concretization of scientific abstract concepts. However, due to the shortage of physical laboratories, there is a need to integrate virtual labs into teaching as an alternative to physical labs to promote students' experiential learning, conceptual understanding, attitude and overall performance. The present study explored how students in secondary schools perceive the use of virtual and physical laboratories in learning biology. The study involved 53 biology students from one secondary school in the Ruhango district in Rwanda. The school was purposively selected to participate in this study as it had an equipped physical laboratory with the materials needed during the study. In addition, the school was equipped with a computer lab where each student had access to a computer. This study used a mixed-method research approach. A validated survey questionnaire of closed-ended questions was used to collect quantitative data. Furthermore, a focus group of eight students (four boys and four girls) was used to collect qualitative data. The data collected was analysed both quantitatively and qualitatively. The results showed that more students perceived virtual lab activities as easier to perform, more motivating and more interesting than physical lab activities. However, 81% of students stressed that virtual labs should not replace physical labs; rather, both should be used in complementarity as physical lab activities helped them to understand the content more than virtual lab activities. Nevertheless, students pointed out that virtual labs could undoubtedly be very helpful for

students whose schools lack physical laboratory equipment. The findings of this study indicate the need for further investigation to compare physical and virtual labs in terms of students' academic performance and interest in biology.

Keywords: students' perceptions; virtual labs; physical science laboratory; secondary schools

1. Introduction

In the biology laboratory, experiments are carried out to show how theoretical concepts can be applied in practice. It has been posited that the biology laboratory enables students to easily make a transition from abstract biology concepts to concrete concepts (Ratamun & Osman, 2018a). This concretization helps students to improve their ability to make connections between the learned theories and the real world. According to Shana and Abulibdeh (2020), laboratory activities develop students' analytical thinking abilities and help them to connect theory to practice. They contend that for students to learn laboratory skills, they must perform genuine experiments in a real laboratory. However, research indicates that physical/real laboratories and their equipment are expensive and difficult to maintain (Daba et al., 2016). Thus, researchers have indicated that teachers are challenged to provide their students with needed laboratory sessions and engage them actively in their learning.

It has been discovered that using a variety of instructional modalities is one way to foster an active learning environment. In light of this, published research has indicated that technology-based instruction like the use of virtual labs motivates students (Kudzai & Pearson, 2015; Oser & Fraser, 2015) and engages them in learning activities by providing them with the opportunity to experience and improve learning. Virtual labs are defined as computer-based activities in which students use a computer interface to engage in an experimental task or other activity (Oser & Fraser, 2015). Virtual labs imitate crucial parts of an experiment and allow students to engage in alternative hands-on activities by moving through the steps, boosting interaction with laboratory scenarios (Radhamani et al., 2014).

The use of virtual labs as alternative tools for laboratory experimentation prompted many controversial arguments and many researchers embarked on assessing their effects on students' learning outcomes in comparison to the physical laboratory. Gambari et al. (2018) indicated that virtual labs-based instruction promotes students' active participation and interest in their learning. The research indicated that a virtual laboratory gives students the chance to improve their practical skills, such as handling materials and equipment, gathering data and interactively completing the experiment process. It also allows students to conduct experiments that were considered as difficult in physical laboratories (Nicol et al., 2022). In addition, research indicates that the use of virtual labs is a way of giving students the chance to perform scientific experiments in various contexts that can add authenticity and foster their interest in science in the future (Falode, 2018).

However, some researchers find a physical lab to be more effective than virtual labs. Ratamun and Osman (2018a) asserted that students' positive attitudes toward biology are more developed via physical practical tasks than virtual activities. Hamed and Aljanazrah (2020) revealed that students appreciate physical labs more than virtual labs as they were helped to develop their critical thinking by reflecting on the tasks and asking questions that were not possible in a virtual experiment. Supporters of the physical lab also confirm that physical experiments impart crucial laboratory processing skills to students than virtual lab experiments. Research indicated that students regard the role of the physical laboratory in a favourable light as it helps them to understand biology concepts. Nevertheless, many different researchers have shown that both laboratories are effective.

Indeed, the research literature is replete with empirical data comparing the impact of science labs both virtual and physical particularly in achieving educational objectives in science. However, the majority of these leave out the experiences and viewpoints of the students. A comparative study on virtual, physical and hybrid laboratories conducted by Son et al. (2016) indicated that there is a strong connection between the student's perceptions of learning biology and their perception of the quality of laboratory activities. Thomas and Meldrum (2018) asserted that comprehending the laboratory environment requires knowing students' experiences and perceptions of the laboratory. It has been demonstrated that students' perspectives, opinions and perceptions are essential to provide vital insights for the adoption of new teaching strategies and for assessing the impact of pedagogical modifications. Thus, the main objective of the current study was to explore students' perceptions of virtual and physical biology laboratory activities and usage in Rwandan secondary schools.

1.1. Study Motivation

Like in many other Sub-Saharan African Countries, currently, there is a shortage of science laboratories in Rwandan schools (Ndihokubwayo, 2017), particularly biology laboratories (Mukagihana et al., 2021). Therefore, this study was conducted with the purpose of investigating students' views about virtual labs and exploring how they perceive the use of virtual labs as alternative laboratory tools that can be a solution to the lack of physical labs and equipment. Furthermore, no similar study has ever been conducted in the context of Rwanda.

1.2. Research Question:

The present study sought to answer the following question:

What are the perceptions and views of secondary school students about virtual and physical laboratory activities and usage in Rwandan secondary schools?

2. Related Literature

2.1. Benefits and Barriers of Physical Laboratory in Science Learning

The physical laboratory, also referred to as a hands-on laboratory, is an effective part of education, especially science education where students acquire both theoretical knowledge and practical skills (Daba et al., 2016; Falode, 2018). In this environment, theories are put into practice and students actively participate in building their knowledge. Literature points out that lab applications help students improve their critical thinking, reasoning and decision-making skills (Nicol et al., 2022). According to Harman et al. (2016), experiments help the students to formulate hypotheses, manipulate variables, interpret results and draw conclusions. Laboratory activities help learners to relate the concepts they are learning to real-world experiences. The laboratory method is one of the methods that enable students to learn through activities, and laboratory practices are very important for a better understanding of abstract concepts (Husnaini & Chen, 2019).

Researchers have indicated that science cannot be meaningful without laboratory work. With the help of laboratory activities and experiments, the information learned becomes embedded in students' minds since the activities allow them to repeat the information presented (George-Williams et al., 2018). The literature indicated that physical laboratory activities have different important functions for students: (1) they foster and sustain student interest in science; (2) they foster their ability to think creatively and solve problems; (3) they foster conceptual understanding and intellectual ability (George-Williams et al., 2018); (4) they encourage scientific thinking and the use of the scientific method (such as formulating hypotheses and making assumptions) (Hawkins & Phelps, 2013); and (5) they foster practical skills (such as designing and carrying out investigations, observations, recording data and analysing and interpreting results) making connections and linking the experiences with current advances in technology. Generally, the purpose of physics lab activities is to help students develop science inquiry skills that can be applied to other areas in problem-solving, to help students understand and, to some extent, emulate the role of the scientist, and to help students develop analytical and critical explanations of scientific phenomena.

However, despite all the above benefits, the literature indicates some drawbacks of physical laboratories that affect learning. According to Awan (2015), in the physical laboratory, some tests might not be able to be finished in the allotted time. Because of insufficient resources, most teachers rely on experiments and it could be challenging for teachers to maintain students' attention while demonstrating experiment outcomes. During demonstrative experiments, some students could choose to remain idle. Students could engage in conversation with one another as the teacher is conducting the experiments. Because of the additional work that laboratories require, such as the preparation of materials and supplies, teachers may favour lecturing instruction. There may be a lack of resources and tools in physical laboratories, which prevents effective experimentation. In crowded classes, it could be challenging to conduct experiments and it is possible that experiments could not provide any results. Experimentation is pricey and testing findings repeatedly might not be possible,

and this could impede students from thinking critically (Darling-Hammond et al, 2019).

2.2. Virtual Laboratory

Virtual labs (VL) are also defined as simulations of real lab experiments whose laboratory equipment is simulated on computers rather than being real (Brinson, 2015). Along with the opportunities brought about by digitalisation, new teaching models are emerging in laboratory applications across all fields of education. Today's information and communication technologies have advanced to the point where they can provide the necessary environments and tools for laboratory applications. In this context, institutions can provide laboratory applications to their students in both traditional and open and distance learning settings using virtual or remote access laboratories.

A VL is the most prevalent type of technology-based laboratory, and, although it has many features in common with a remote laboratory, they are quite different (Alkhaldi et al, 2016; Brinson, 2015). A remote laboratory, according to Alkhaldi et al (2016) is a laboratory in which learners can conduct experiments remotely within a physical laboratory by connecting to the physical laboratory via a network. Experiments in remote laboratories are conducted away from the experimenter. On the other hand, a VL is a virtual environment simulated by using computer programs that students can use to conduct experiments. A VL can also be referred to as a simulated laboratory. VLs are interactive learning environments that use computer technologies, simulations and a variety of instructional technologies to digitise physical laboratory activities.

Literature indicates many different advantages associated with the use of VLs in science education. However, the literature indicates also several disadvantages of the virtual laboratory. For ease of comparison, the following table summarises the advantages along with disadvantages associated with them

Table 1: Reviewed advantages and disadvantages associated with the use of virtual labs

Advantages	**Literature source**
Allow students to do the experiences that are not possible in a physical laboratory	(Olympiou et al., 2013)
Improve students' conceptual understanding	(Byukusenge et al 2022)
Provide immediate feedback	(Olympiou et al., 2013)
Enhance students' attitudes toward science	(Ambusaidi et al, 2018)
Allow students to study science at their own pace	(Alkhaldi, Pranata, & Athauda, 2016)
Improve students' self-efficacy and confidence in the laboratory	(Reeves & Crippen, 2021)
Helpful as a preparatory tool and allow experiment repetition	(Dyrberg et al., 2017)
Provide students with safe environments during practices	(Ambusaidi et al., 2018)
Make learning easier by reducing cognitive load	(Olympiou et al., 2013)
They are cost-effective	(Alkhaldi et al., 2016)
Useful for visual learners	(De Jong, Linn, & Zacharia, 2013)

Advantages	Literature source
Enhance students' manipulative skills	(Makransky et al., 2019)
Disadvantages	**Literature Sources**
Lack of opportunity to learn appropriate laboratory manipulative skills and experimental procedures	(Faour et al., 2018)
Students work in an overly idealised setting	(Ratamun & Osman, 2018b)
Students using VLs might think they are playing a video game	(Ambusaidi et al., 2018)

3. Research Methodology

The methodology used for this study was quasi-experimental using one group in a post-test-only design where, after laboratory (physical and virtual) teaching, a post-lab survey was given to the students. The quantitative data collected from the survey were complemented by qualitative data from participants through a focus group interview (Creswell, 2012**).** The approach of collecting mixed data (quantitative and qualitative) was based on the idea that employing either qualitative or quantitative alone does not provide a complete grasp of the study subject (Creswell, 2015).

3.1. Research Instrument

This study used a survey questionnaire that consists of 19 items (see Appendix 1). These items were arranged in three sections. The first section consisted of four items that aimed to assess students' views about actual laboratory learning. The second section comprised 10 items that were given to students after doing a series of activities in the physical lab and virtually by using simulated experiments. The third section comprised five items that were designed to assess how students perceived VLs in comparison to physical labs. The face and content validity of the questionnaire was checked by experts in educational research at University of Rwanda. An inter-rater reliability check was used and a substantial reliability rate of .79 as a value of Cohen's Kappa (k) was found. The research also used a focus group interview that was conducted with a group of eight students (four boys and four girls).

3.2 Study Participant and Data Collection Procedure

Data was collected from senior six students who were studying biology as a major subject in the combination of mathematics, chemistry, and biology (MCB). Fifty-three students participated in this study. These students were from one secondary school selected in the Ruhango district. This school was chosen because it had a physical laboratory equipped with the material that was needed during this study. Before any laboratory (physical and virtual) activity, all students were given a pre-survey questionnaire to investigate their views about actual learning in the physical laboratory. After a series of physical and VL activities, all students were given a post- lab survey and among them, eight students were chosen by their colleagues to participate in a focus group interview for further understanding of their perceptions. Figure 1 indicates the procedure of data collection.

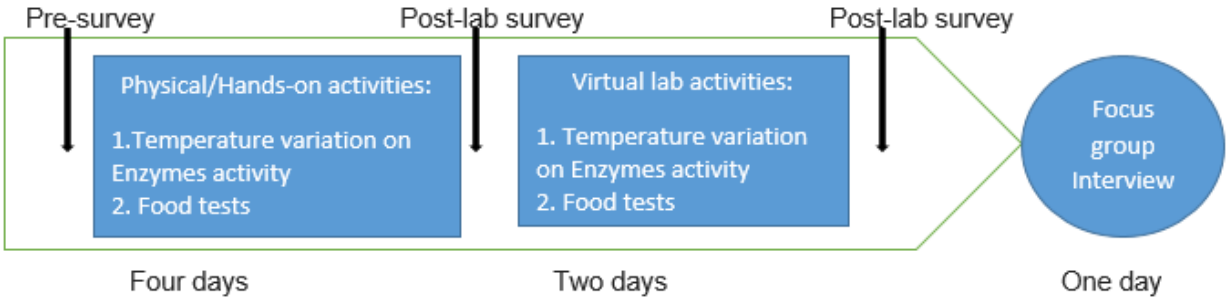

Figure 1: Data collection framework

The study complied with research ethics. Every potential participant was free to decide whether or not to participate in the research. The participants were told that they were free to withdraw from the research at any time without suffering any consequences.

3.3. Description of Laboratory Activities

The laboratory sessions comprised six experiments. The first session comprised two experiments to investigate the impact of temperature ranges on the activity of catalase enzymes. The second session comprised four experiments on food tests to identify food nutrients. Those were: testing for fats, testing for starch, testing reducing sugar (Glucose), and testing for proteins. Those topics were selected because the practical activities related to them could be performed in normal school laboratories but are not performed due to the scarcity of physical laboratory equipment in Rwandan secondary schools. Bearing that in mind, the corresponding virtual experiments were searched and performed to identify if they could be viable options to replace physical experiments.

Description of physical lab activities

First of all, the students were divided into 10 groups of five except two groups which consisted of six students each. Since the groups were mixed, male and female students collaborated. Regarding the experiment on the impact of temperature on enzyme (catalase) activity, the first five groups worked on the first day, while the remaining five groups worked on the second day. This plan was made as there needed to be adequate room in the lab for each student to participate in and follow each step of the experiment without interruption. The experiments entailed the preparation of a mashed liver sample, heating and measuring.

Each group received all the necessary laboratory supplies, including chemicals and a protocol for the lab activity. All sessions were facilitated by two biology teachers, and the first author oversaw all of the activities. All experiment-related tasks, including the report, were due by the end of the allotted 80 minutes for the biology lesson in the classroom timetable. The second experimentation session focused on identifying the food nutrients. Four days were needed to carry out these experiments so we had to use the biology class periods that were allotted on the school timetable. Two days were dedicated to testing for lipids and starch, while the remaining two days were devoted to testing for reducing sugar (*glucose*) and proteins

Description of virtual labs

We first conducted a comprehensive search and review of available virtual experiments that corresponded to the experiments performed by students in the physical lab. These experiments were related to enzymes and testing food for nutrients. It should be noted that the virtual experiments used in this study were 2D screen-based simulations. During this study, we did not use an immersive 3D virtual lab because we could not access it. These VLs were prepared by Myidea company and we accessed them online. For enzyme activity, a series of virtual experiments on the impact of temperature changes on the activity of the enzyme (catalase) were performed. These comprised interactive experiments where students were first given the instructions and protocol of the experiment. Before starting the virtual experiment, students were given the background of the activity, the list of equipment needed, the aim of the experiment, the hypothesis, the risk assessment and the method to be used in general.

For the VLs related to food tests, the following tests were carried out: testing for fats on brown paper; testing for fats by using Sudan III solution (Sudan Red); testing for starch using Lugol's iodine solution; testing for glucose (Reducing sugar) by using Benedict's solution; and testing for proteins by using Biuret reagent. All these virtual experiments were done in two days based on the normal classroom timetable.

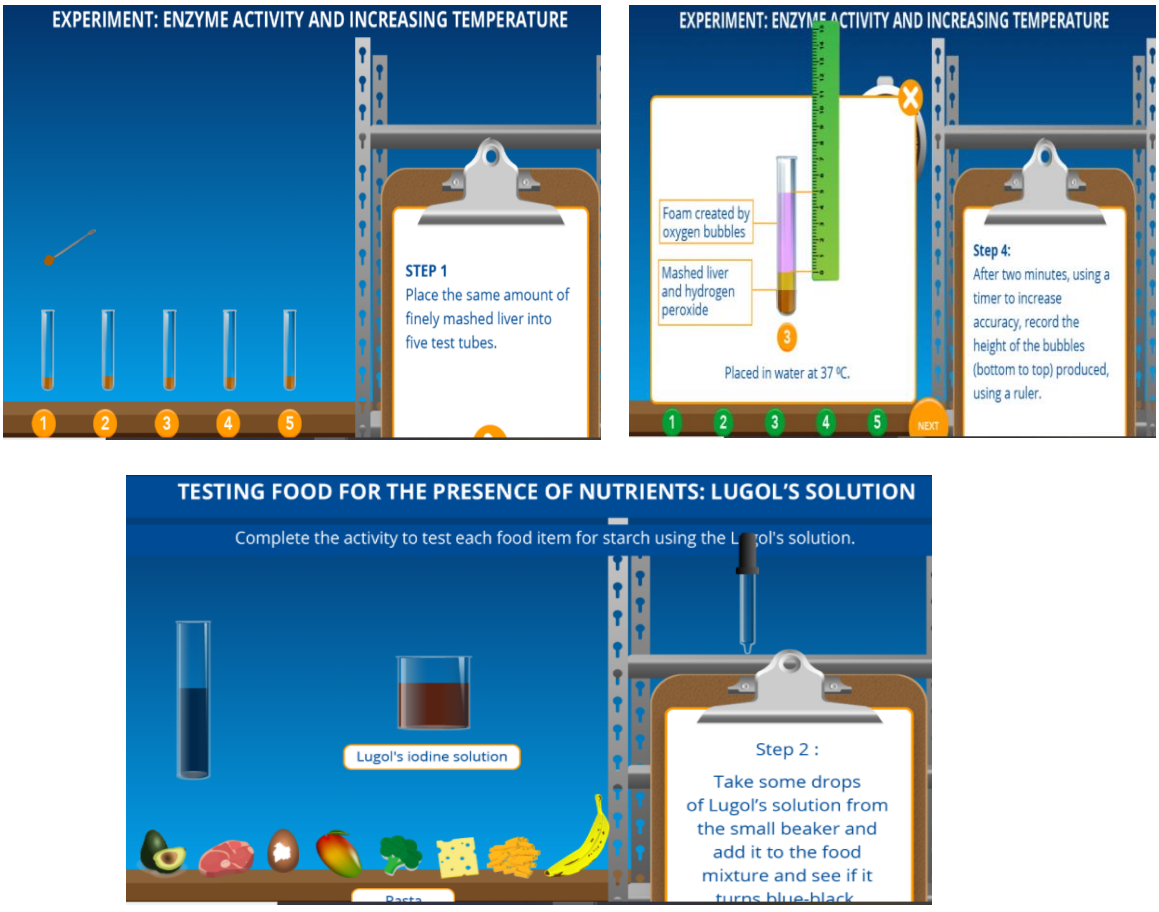

Figure 2. Screen captures from Myidea virtual labs

3.3. Data Analysis

The collected data were analysed by using Microsoft Excel 16. The "Count if" function was used to calculate the number of answers for each statement. We counted and combined those who replied Strongly Agree and Agree to calculate the percentage of agreement whereas Strongly Disagree and Disagree were counted and combined to calculate the disagreement percentage for each statement. Responses from focus group interviews were analyzed to complement quantitative data.

4. Results

Student's preparedness and usage of laboratory

The results presented in figure 3 indicate students' responses during a pre-lab survey. The results indicate that most students (91%) agreed that laboratory activities should always be done in their biology courses. However, 92% of students indicated that they rarely performed physical lab activities and all students showed that they had never carried out virtual lab activities.

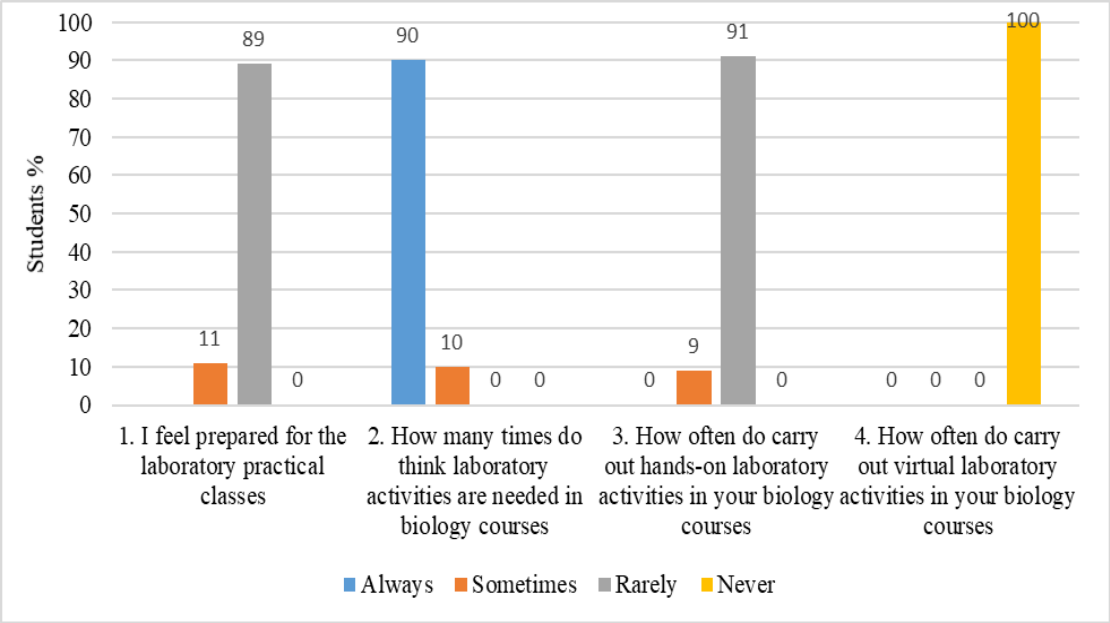

Figure 3: Students' actual usage of the laboratory (physical and virtual)

The results presented in Figure 4 indicate students' responses to the post-lab survey questions evaluating their perceptions about practical activities done in physical and in VLs. The responses were rated on a 5-point Likert rating scale from Strongly Agree to Strongly Disagree. However, in the presentation, Strongly Agree and Agree were combined as agreement while Strongly Disagree and Disagree were combined as disagreement.

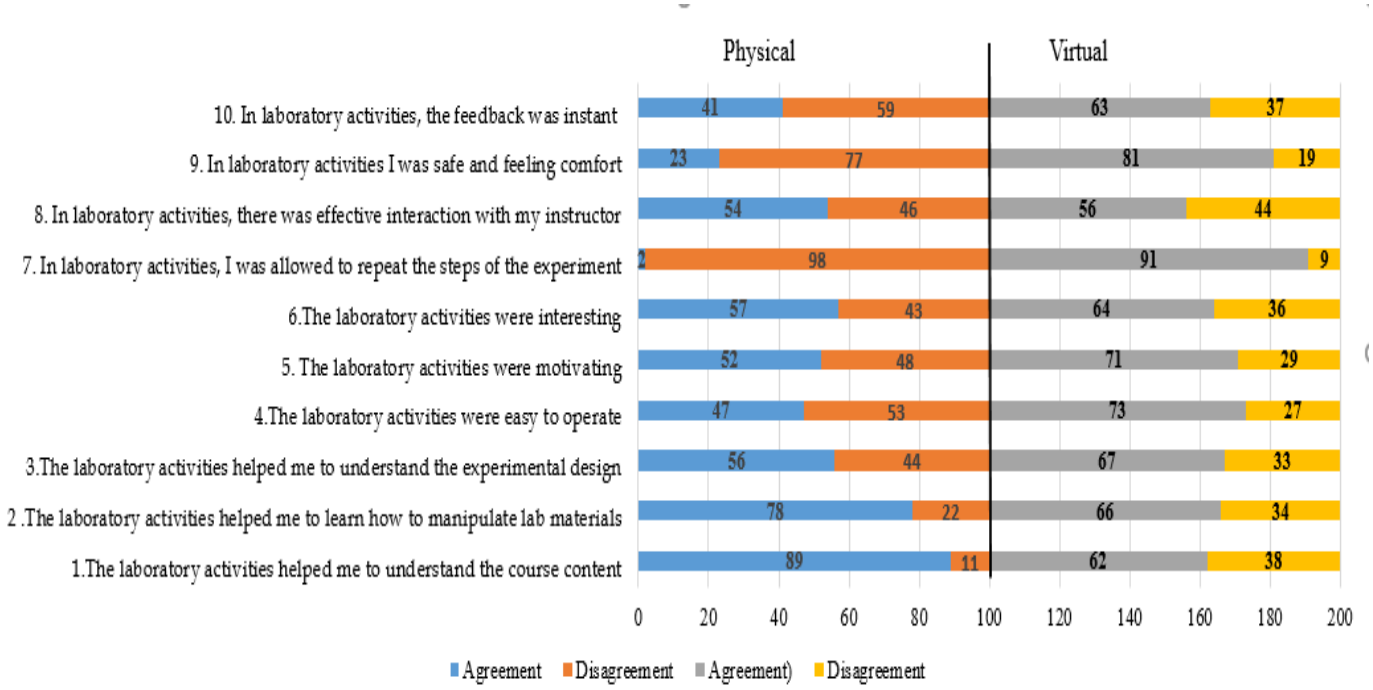

Figure 4: Overall students' perceptions about the post-lab survey items

The results indicate that the majority of students confirmed that lab activities helped them to understand the concept of enzyme activities and food nutrient identification with percentages of 89% and 62% in physical labs and VLs respectively. The results also showed that laboratory activities helped the students to learn how to manipulate laboratory materials. To this end, 78% of students in the physical labs and 66% in the VLs agreed with the statement that "laboratory activities helped me to learn how to manipulate laboratory materials".

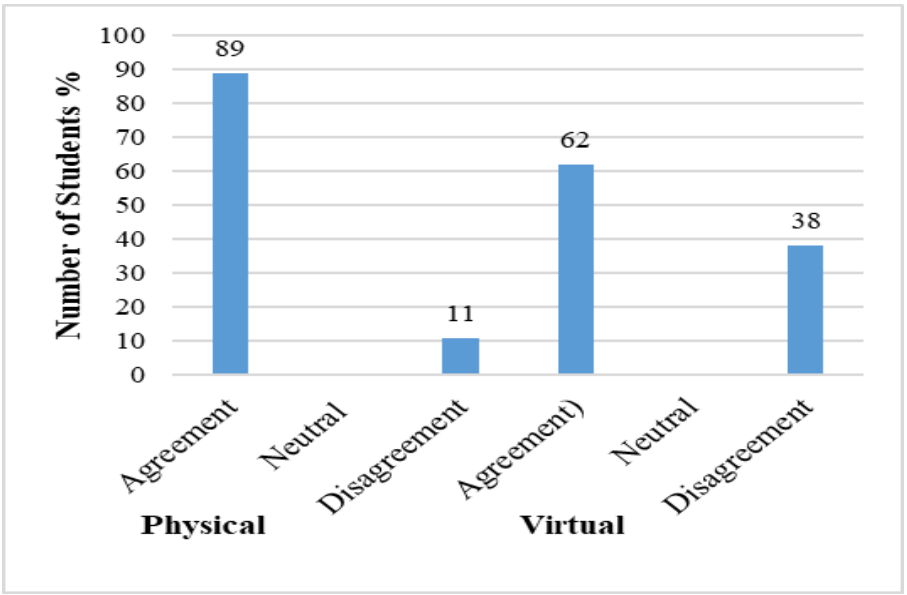

Figure 4.a: Laboratory activities helped me to understand the concepts

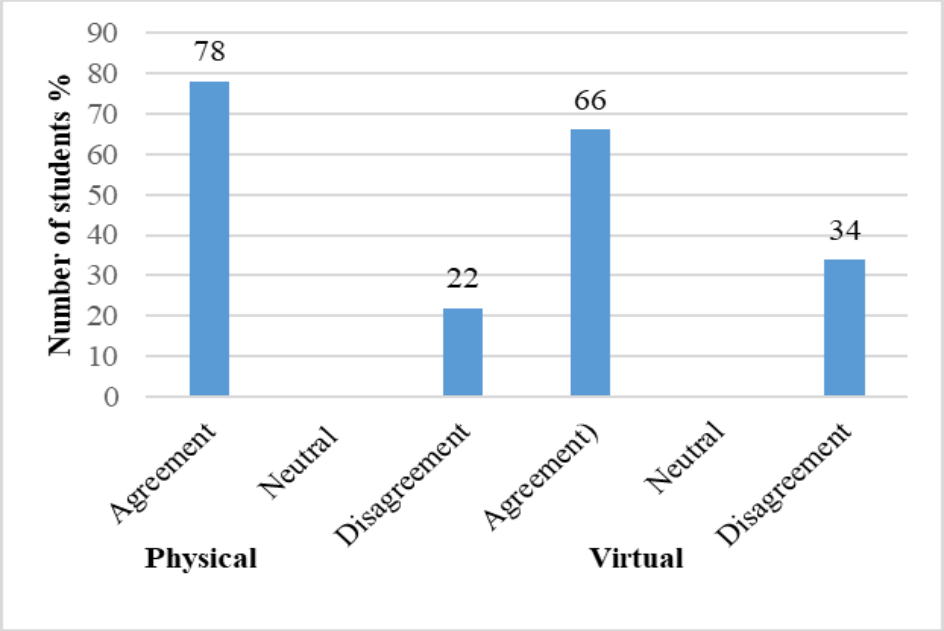

Figure. 4.b. Laboratory activities helped me to learn how to manupulate lab materials

The above result was supported by the responses of students in the focus group interview after completing all laboratory sessions. In this study, students indicated that with physical lab activities, the content was understood better than with virtual laboratory activities. Some students said:

> *I found the exercises relating to how temperature affects catalase activity to be quite clear, which made it easier for me to comprehend the topic and realise that liver tissue contains the catalase enzyme. Before experimenting, it was too abstract and challenging to comprehend that enzymes exist in living cells, but I witnessed firsthand how the foam was created from the mashed liver.*
>
> *...though I did enjoy it, I found that the physical lab exercises were more helpful for me in understanding the concept of catalase activity than the computer-based activities.*

Student's perceptions of laboratory usability

The results also indicated that virtual lab activities were easier to operate than physical lab activities. As Figure 4c shows, the majority of students (73%) indicated that virtual or simulated activities were easier to do than physical lab activities and 53% indicated that physical lab activities were easier to do than virtual ones. Furthermore, the results also indicated that the virtual activities helped students to understand the experimental design more than physical lab activities did as is clearly indicated in Figure 4d.

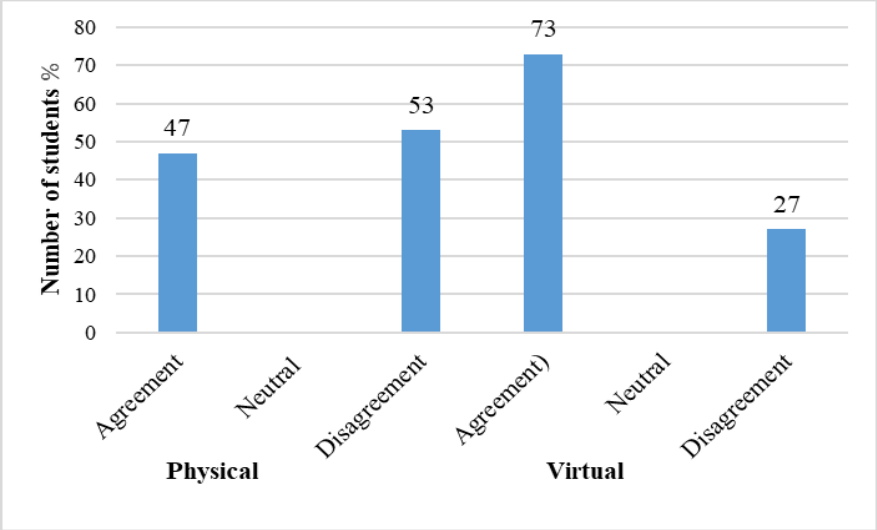

Figure 4.c. Laboratory activities are easier to operate

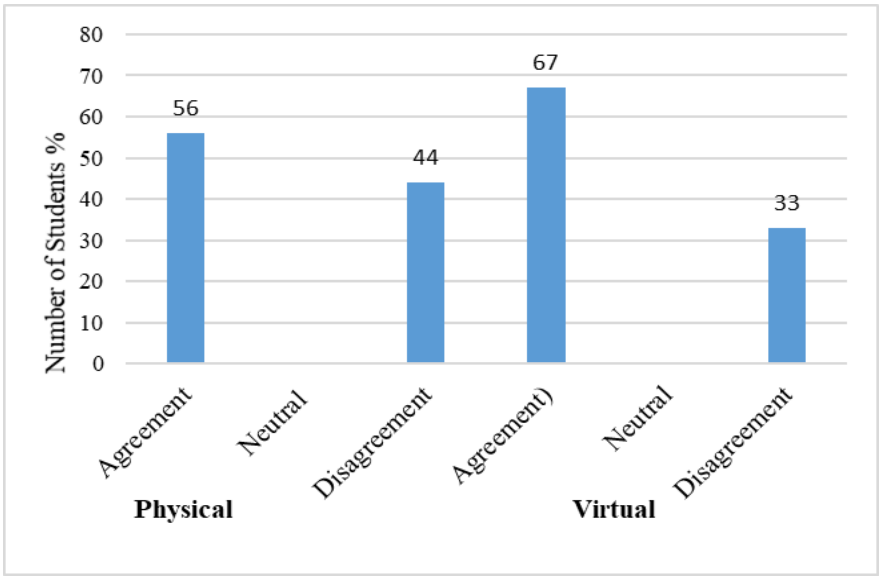

Figure 4.d. The laboratory activities helped MEe to understand the experimental design

These results are also supported by the responses in the interview:

> *The computer-based activities were easy to be done, and the instructions for the activities were clear and precisely well explained on the sheet that was displayed for each step of the activity.*
>
> *I liked how everything was clearly explained before you clicked the experiment start button. A nice orientation was provided right at the start of the session. Knowing what to do next was not difficult.*

The results of this study indicate the interaction between students and the teacher during the physical laboratory activities and during virtual laboratory activities was almost the same. 54% of students confirmed that during physical activities, they were effectively interacting with their teacher while 56% indicated that they interacted well with the teacher during virtual activities.

Furthermore, 63% of students indicated that the feedback during physical lab activities was very quick (Figure 4f) compared to the feedback in VLs where 51% agreed with the statement.

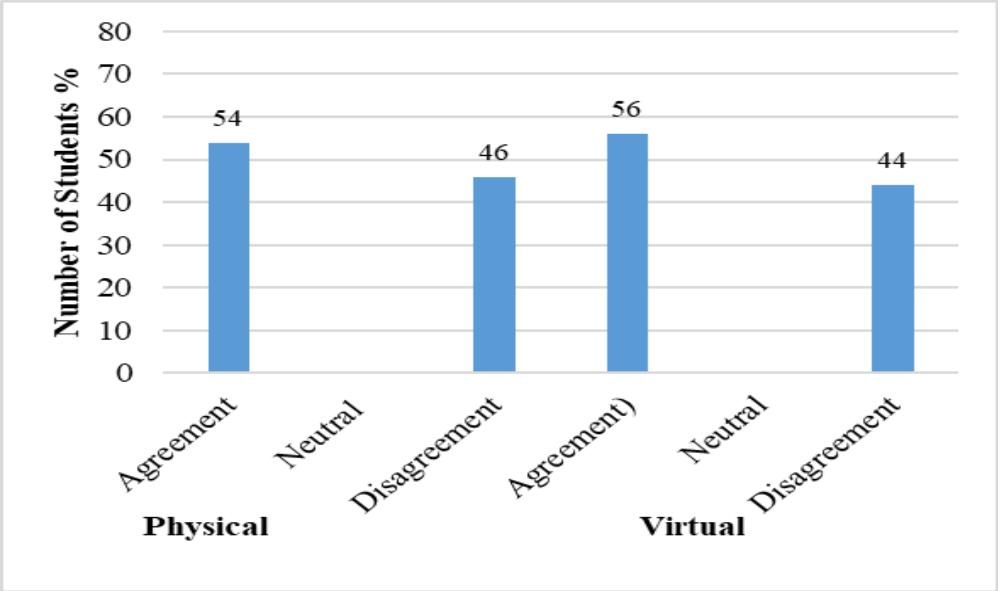

Figure 4.e. During lab activities, there was effective student-teacher interaction

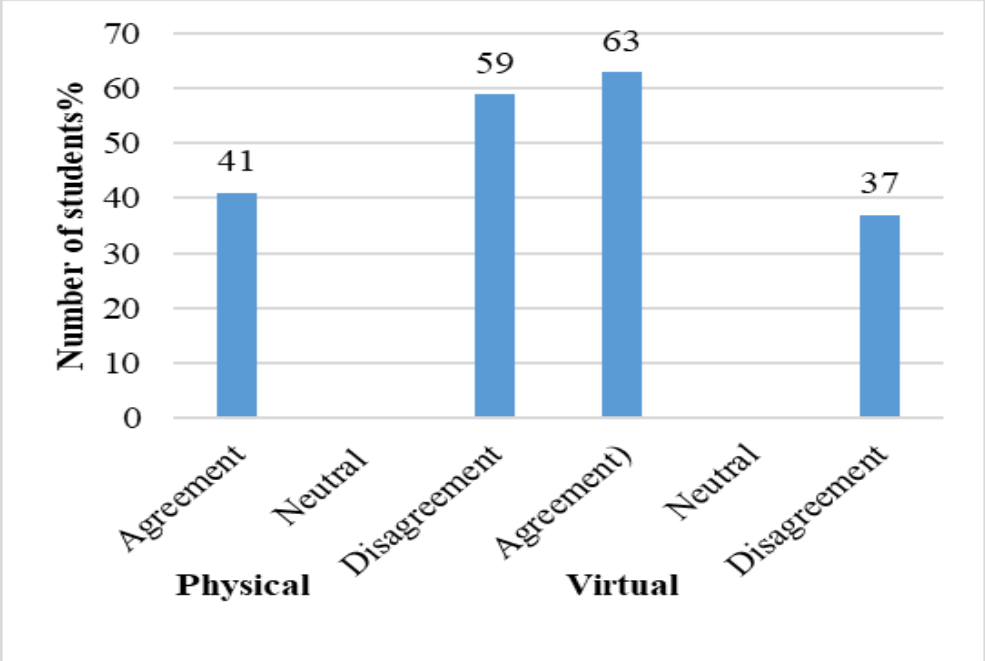

Fig 4.f. During lab actibities the feedback was instant

Figure 5 presents the student's responses to the part of the post-lab survey that comprised 5 questions to assess how they perceived VLs compared to physical labs. The results indicated that most of the students 78% disagreed with the idea that VLs should replace physical labs in biology. However, the results showed that most of the students (81%) supported the statement that both virtual and physical labs should be offered. Though 61% of students agreed that they could

encourage other students to use VLs, in this study, 56 % disagreed with the statement "I can prefer VLs to the physical lab".

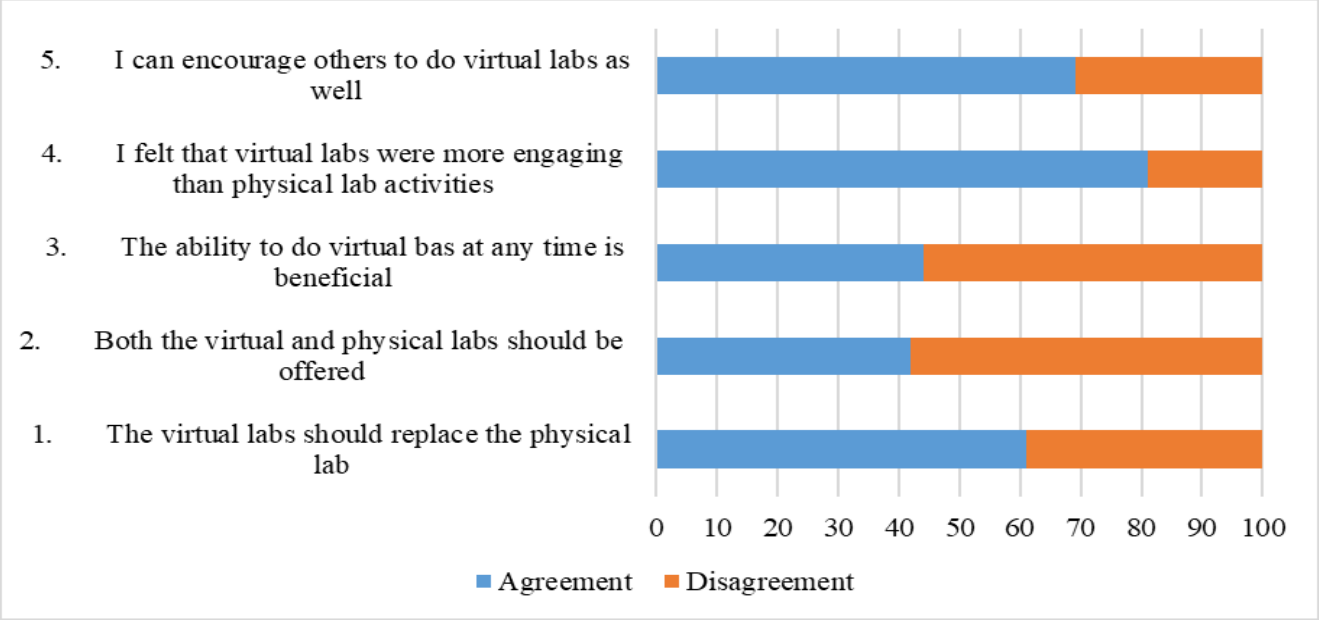

Figure 5: Students' perceptions and views about virtual labs in comparison to physical labs

Students' views in the focus interview were also captured. Some students pointed that:

> *"I enjoyed how virtual activities were easy to be done. They were organised in a simple manner that was easy to understand but I felt like I can prefer to use them together with physical activities and they can help me better perform physical lab activities".*

> *"Our school has a physical lab, but for whatever reason, I can't explain, we seldom conduct experiments there. Instead, our teacher frequently utilizes a computer and a projector in a smart classroom. Although virtual labs are not enough to teach the necessary practical skills, I believe that they can inspire even our teacher to make plans for laboratory preparation".*

> *"I think that virtual experiments are really very helpful, especially for the students whose schools do not have physical, and even for us who has physical lab but because we have to learn and understand the fundamental lab skills, the physical lab should be maintained".*

5. Discussion

The use of VLs in science education has been proposed as a solution to the scarcity of physical labs. The present study was conducted to explore the perceptions of Rwandan secondary school students about the use of VLs in teaching biology compared to the use of physical labs. The students in the current study claimed that they were unfamiliar with VLs before being taught

(before intervention), but they also demonstrated that they hardly ever conducted physical experiments in their learning. However, after teaching, the students showed different views about virtual and physical lab activities.

The findings of this study revealed that students acknowledged the positive impact of both types of laboratories on conceptual understanding. They indicated that the laboratory experiments helped them to understand the content but they stated that physical laboratory activities helped them more than VLs. These findings are consistent with prior research findings. Husnaini and Chen (2019) showed that physical labs and VLs were equally successful in teaching difficult concepts. However, contrary Wang et al. (2015) claimed that the use of virtual experiments may enhance students' conceptual knowledge more than real experiments.

The findings of the present study also indicated that VLs helped students to understand the experimental design and they were easier to operate than physical lab activities. Falode (2018) showed that the virtual laboratory was simple to use for the participants. The ease of use of VLs is supported by Abu-Dalbouh (2013) who said that adopting a particular technology should not require any physical or mental effort. In the interview, students said that all steps in virtual activities were more clearly explained than they were in physical lab activities. The students in the present study asserted that VL activities were motivating and interesting. Students were interested in interacting with ICT tools. Research indicates that laboratory activities encourage and motivate students to engage in scientific inquiry and boost their interest in science (Shana & Abulibdeh, 2020). The use of and interaction with ICT tools was the first reason that interested the students.

Other important findings from this study show that students were open and had positive intentions to use VLs for their learning. However, the idea that VLs should be used in addition to physical labs was emphasised. It was found that 56% disagreed with the statement that VLs should replace physical labs but 81% of students agreed that both virtual and physical lab activities should be offered. In their responses during the focus group, students highlighted that VLs were very important educational tools that could help them to grasp the content and gain important practical skills. In particular, students said that VLs could be very helpful in schools that lack physical labs as alternatives to physical lab materials, while in schools that have physical labs, VLs can serve as lab supplements. One student said: "*In fact, the experiments we conducted virtually were very interesting and useful. I was able to navigate and repeat the steps without encountering any difficulties, which made it easier for me to read and comprehend the experimental procedure and become familiar with the virtual materials used. But physical experiments particularly about enzymes was also fantastic. However, I wish my colleagues from the schools which do not have laboratories can also be allowed to use virtual experiments*". As suggested by Abu-Dalbouh (2013) when people have a positive intention to use a specific technology has an impact on how they use it.

6. Conclusion

This study aimed to explore the perceptions of students about the use of physical and VLs for laboratory biology experiments. The study indicated that students had positive perceptions of using VLs. However, the majority of respondents claimed that VLs could not replace practical labs; instead, both should be used. Particularly, students perceived VLs as helpful resources in the schools that lack physical laboratories. The benefits of VLs can be realized by schools and institutions that lack the financial resources to establish physical laboratories. The findings are significant for instructional designers, VL creators and educators in general.

7. Recommendations

The present study did not compare the effect of physical laboratories and VLs on students' academic achievement. Even though we assessed how students perceived VLs activities compared to physical labs activities, the sample size involved in this part of the study was too small for the results to be generalised. In addition, it involved a single group of participants could have created bias in finding. Thus, we recommend further research on comparing physical and VLs in terms of students' academic achievement and interest in biology. Further research could also look into the impact of hybrid or blended laboratories on students' achievement and attitudes in learning biology.

8. References

Abu-Dalbouh, H. M. (2013). A questionnaire approach based on the technology acceptance model for mobile tracking on patient progress applications. *Journal of Computer Science*, *9*(6), 763-770. https://doi.org/10.3844/jcssp.2013.763.770

Alkhaldi, T., Pranata, I., & Athauda, R. I. (2016). A review of contemporary virtual and remote laboratory implementations: observations and findings. *Journal of Computers in Education*, *3*(3), 329–351. https://doi.org/10.1007/s40692-016- 0068-z

Ambusaidi, A., Al-Mosawi, A., Al-Balushi, S., & Al-Balushi, K. (2018). The impact of virtual lab learning experiences on 9th grade students' achievement and their attitudes towards science and learning by virtual lab. *Journal of Turkish Science Education*, *15*(2), 13–29. https://doi.org/10.12973/tused.10227a

Awan, M. N. (2015). Physical conditions of science laboratories and problems faced by science teachers in conducting practicals in Punjab. *Bulletin of Education and Research*, *37*(1), 47–54.

Brinson, J. R. (2015). Computers & education learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories : A review of the empirical research. *Computers & Education*, *87*, 218–237. https://doi.org/10.1016/j.compedu.2015.07.003

Byukusenge, C., Nsanganwimana, F., & Paulo Tarmo, A. (2022). Difficult topics in the revised biology curriculum for advanced level secondary schools in Rwanda: teachers' perceptions of causes and remedies. *Journal of Biological Education*, *00*(00), 1–17. https://doi.org/10.1080/00219266.2021.2012225

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Boston, MA: Pearson Education, Inc

Creswell, J. W. (2015). *Educational research: Planning, Conducting, and Evaluating Quantitative and Qualitative Researc*h. NewYork: Pearson.

Daba, T. M., Anbassa, B., Oda, B. K., & Degefa, I. (2016). Status of biology laboratory and practical activities in some selected secondary and preparatory schools of Borena

zone, South Ethiopia. *Educational Research and Reviews*, *11*(17), 1709–1718. https://doi.org/10.5897/ERR2016.2946

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97-140. https://doi.org/10.1080/10888691.2018.1537791

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, *340*(130), 305–308. https://doi.org/https://doi.org/10.1126/science.1230579

Dyrberg, N. R., Treusch, A. H., & Wiegand, C. (2017). Virtual laboratories in science education: students' motivation and experiences in two tertiary biology courses. *Journal of Biological Education*, *51*(4), 358–374. https://doi.org/10.1080/00219266.2016.1257498

Falode, O. C. (2018). Pre-service teachers' perceived ease of use, perceived usefulness, attitude and intentions towards virtual laboratory package utilization in teaching and learning of physics. *Malaysian Online Journal of Educational Technology*, *6*(3), 63–72. https://doi.org/10.17220/mojet.2018.03.005

Faour, M.A. & Ayoubi, Z. (2018). The effect of using virtual laboratory on grade 10 students' conceptual understanding and their attitudes towards physics. *Journal of Education in Science, Environment and Health (JESEH)*, 4(1), 54-68. DOI:10.21891/jeseh.387482

Gambari, A. I., Kawu, H., & Falode, O. C. (2018). Impact of virtual laboratory on the achievement of secondary school chemistry students in homogeneous and heterogeneous collaborative environments. *Contemporary Educational Technology*, *9*(3), 246–263. https://doi.org/10.30935/cet.444108

George-Williams, S. R., Karis, D., Ziebell, A. L., Kitson, R. R. A., Coppo, P., Schmid, S., Thompson, C. D., & Overton, T. L. (2018). Research and practice students ' experiences in teaching laboratories through the lens of meaningful learning. *Chemistry Education Research and Practice*. https://doi.org/10.1039/c8rp00188j

Hamed, G., & Aljanazrah, A. (2020). The effectiveness of using virtual experiments on students' learning in the general physics lab. *Journal of Information Technology Education: Research*, *19*, 977–996. https://doi.org/10.28945/4668

Harman, G., Cokelez, A., Dal, B., & Alper, U. (2016). Preservice science teachers' views on laboratory applications in science education: The effect of a two-semester course. *Universal Journal of Educational Research*, 4(1), 12-25. https://doi.org/ 10.13189/ujer.2016.040103

Hawkins, I., & Phelps, A. J. (2013). Virtual laboratory vs. traditional laboratory: Which is more effective for teaching electrochemistry? *Chemistry Education Research and Practice*, *14*(4), 516–523. https://doi.org/https://doi.org/10.1039/c3rp00070b

Husnaini, S. J., & Chen, S. (2019). Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment. *Physical Review Physics Education Research*, *15*(1), 10119. https://doi.org/10.1103/PhysRevPhysEducRes.15.010119

Kudzai, C., & Pearson, C. (2015). Virtual laboratories - A solution for tertiary science education in Botswana? *European Journal of Logistics Purchasing and Supply Chain Management*, *3*(1), 29–40.

Makransky, G., Mayer, R. E., Veitch, N., Hood, M., Christensen, K. B., & Gadegaard, H. (2019). Equivalence of using a desktop virtual reality science simulation at home and in class. *PLoS ONE*, *14*(4), 1–14. https://doi.org/10.1371/journal.pone.0214944

Mukagihana, J., Nsanganwimana, F., & Aurah, C. M. (2021). How pre-service teachers learn microbiology using lecture, animations, and laboratory activities at one

private university in Rwanda. *International Journal of Learning, Teaching and Educational Research*, *20*(7), 328–345. https://doi.org/https://doi.org/10.26803/ijlter.20.7.18

Ndihokubwayo, K. (2017). Investigating the status and barriers of science laboratory activities in Rwandan teacher training colleges towards improvisation practice. *Rwandan Journal of Education*, *4*(1), 47–54.

Nicol, C. B., Gakuba, E., & Habinshuti, G. (2022). Students' Opinions, views, and perceptions of science laboratory learning: A systematic review of the literature. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(3), 2–17. https://doi.org/10.29333/ejmste/11793

Olympiou, G., Zacharias, Z., & deJong, T. (2013). Making the invisible visible: Enhancing students' conceptual understanding by introducing representations of abstract objects in a simulation. *Instructional Science*, *41*(3), 575–596. https://doi.org/10.1007/s11251-012-9245-2

Oser, R., & Fraser, B. J. (2015). Effectiveness of virtual laboratories in terms of learning environment, attitudes and achievement among high- school genetics students. *Curriculum and Teaching*, *30*(2), 65–80. https://doi.org/10.7459/ct/30.2.05

Radhamani, R., Sasidharakurup, H., Sujatha, G., Nair, B., Achuthan, K., & Diwakar, S. (2014). Virtual labs improve student's performance in a classroom. *E-Learning, E-Education, and Online Training*, *138*, 138–146. https://doi.org/doi:10.1007/978-3-319-13293-8_17

Ratamun, M. M., & Osman, K. (2018a). The effectiveness comparison of virtual laboratory and physical laboratory in nurturing students' attitude towards chemistry. *Creative Education*, *09*(09), 1411–1425. https://doi.org/10.4236/ce.2018.99105

Ratamun, M. M., & Osman, K. (2018b). The effectiveness of virtual lab compared to physical lab in the mastery of science process skills for chemistry experiment. *Problems of Education in the 21st Century*, *76*(4), 544–560.

Reeves, S. M., & Crippen, K. J. (2021). Virtual laboratories in undergraduate science and engineering courses: A systematic review, 2009–2019. *Journal of Science Education and Technology*, *30*(1), 16–30. https://doi.org/10.1007/s10956-020-09866-0

Shana, Z.J., & Abulibdeh, E. (2020). Science practical work and its impact on students' science achievement. *Journal of Technology and Science Education*, *10*(2), 199–215. https://doi.org/10.3926/jotse.888

Son, J. Y., Narguizian, P., Beltz, D., & Desharnais, R. A. (2016). Comparing physical, virtual, and hybrid flipped labs for general education biology. *Online Learning Journal*, *20*(3), 228–243. https://doi.org/10.24059/olj.v20i3.687

Thomas, G., & Meldrum, A. (2018). Students' perceptions of changes to the learning environments of undergraduate physics laboratories: An empirical study. *Interactive Technology and Smart Education,* 15(4), 165-180. https://doi.org/10.1108/ITSE-10-2017-0045

Wang, J., Guo, D., & Jou, M. (2015). Computers in human behavior. A study on the effects of model-based inquiry pedagogy on students ' inquiry skills in a virtual physics lab. *Computers in Human Behavior*. https://doi.org/10.1016/j.chb.2015.01.043

Appendix

Dear participant, this questionnaire was designed for you to gather your perceptions about biology laboratory activities both physical and virtual. You are requested to respond by ticking in the appropriate place for each statement. There is no right or wrong answer just indicate your true opinion.

Student name …….

School…

Date…

I. Pre-lab survey items

	Always	Sometimes	Rarely	Never
1. To what extent do you feel prepared to undertake laboratory practical classes				
2. How many times do you think laboratory activities are needed in biology courses				
3. How often do you carry out hands-on laboratory activities in your biology courses				
4. How often do you carry out virtual lab activities in your biology courses				

II. Post-lab survey items

Laboratory	Physical						Virtual				
	SD	D	N	A	SA		SD	D	N	A	SA
1. The laboratory activities helped me to understand the course content											
2. The laboratory activities helped me to learn how to manipulate lab materials											
3. The laboratory activities helped me to understand the experimental design											
4. The laboratory activities were easy to operate											
5. The laboratory activities were motivating											
6. The laboratory activities were interesting											

7. In laboratory activities, I was allowed to repeat the steps of the experiment											
8. In laboratory activities, there was effective interaction with my instructor											
9. In laboratory activities I was safe and feeling comfort											
10. In laboratory activities, the feedback was instant											

To what extent do you agree with the following statements?

	SA	A	N	D	SD
1. The virtual labs should replace the physical lab					
2. Both the virtual and physical labs should be offered					
3. The ability to do virtual bas at any time is beneficial					
4. I felt that virtual labs were more engaging than physical lab activities					
5. I can encourage others to do virtual labs as well					