Website:www.jriiejournal.com ISSN 2520-7504 (Online) Vol.6, Iss.4, 2022 (pp. 249 - 258)

Effects of Virtual Laboratories on Students' Conceptual Understanding of Biology in Selected Secondary Schools of Rwamagana District, Rwanda

Diane Uwitonze and Gabriel Nizeyimana
African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science, College of Education, University of Rwanda
Email: uwitodiane@yahoo.fr/ tunize09@gmail.com

Abstract: *The main purpose of this research was to investigate the effects of virtual laboratories on students' conceptual understanding of biology with an emphasis on the foetal developmental process. Quasi-experimental design under a quantitative method was employed. A biology achievement test (BAT) via pre-posttest was used for data collection. Four secondary schools from Rwamagana district, with 162 students, were purposively selected based on the availability of smart classrooms, computers, projectors, and internet connectivity. From these schools, the experimental and control groups were selected randomly with 81 students in each group. Data were analyzed through descriptive statistics and independent sample t-tests using a statistical package for social science (SPSS). The results reveal that the students in the experimental group who were administered virtual laboratory instructions achieved higher mean scores than the students in the control group who taught using the traditional lecturing method (chalk-talk method) at [t (160) = -.540, p = 0.000; p<.05]. This indicates that virtual laboratories in teaching biology concepts have a greater impact on students' conceptual understanding. The study recommends biology teachers to strive to use virtual laboratories in teaching biology as an alternative way of improving students' conceptual understanding of abstract concepts. Further study should explore the contribution of virtual laboratories on the student's conceptual understanding of other difficult and abstract biology topics towards students' conceptual understanding.*

Keywords: *Virtual laboratory, Biology, Foetal development, Effects, Students' conceptual understanding, Secondary schools*

Uwitonze, D. and Nizeyimana, G. (2022). Effects of virtual laboratories on students' understanding of biology in selected secondary schools of Rwamagana District, Rwanda. *Journal of Research Innovattion and Implications in Education, 6*(4), 249 – 258.

1. Introduction

The science of biology is a discipline that greatly contributes to scientific and economic development of nations by addressing particular conditions in society (Awosika, 2008). Biology is regarded as a foundational subject that prepares students for the real wirld of work through different working areas such as medicine, agriculture, industries, food science, pharmaceuticals, and environmental studies (REB, 2015). In this regard, biology is a science subject that can assist countries to achieve their goals of sustaining education that is compatible with socioeconomic and technological demands (Ministry of Education, 2018).

However, most biological concepts are abstract. For instance, the process of human development is relatively abstract and complex, with many knowledge points and large periods (Guo, 2018). It is often a challenging topic for the students to understand fully and master in time. Therefore, multivariate learning strategies, such as inquiry-based learning, laboratory approach, discovery, and

cooperative learning, are considered as the best teaching and learning methods. All these strategies are learner-centered and have the potential to enable students' in-depth comprehension of scientific concepts in general and biology. For this reason, in terms of science-active learning, Rwanda implemented CBC in 2016 changing from knowledge-based to competence-based learning to fulfill the development of students' self-directed, practices of lifelong learning, suitable skills, and knowledge as well as the capacity to use those skills in day-to-day life situation (Ndihokubwayo & Habiyaremye, 2018). Additionally, this new approach to teaching and learning promotes inclusiveness, cooperative learning, and active engagement in learning activities through a learner-centered approach.

Active learning enhances students' understanding, and retention of information, and aids them to improve critical thinking and problem-solving skills (Ndihokubwayo, 2017). From this perspective, laboratory activities are essential to stimulating students' interest and developing scientific skills (Ndihokubwayo et al., 2019). Laboratory work helps students learn science by acquiring conceptual and theoretical knowledge, as well as by building an awareness of the nature and methods of science (Ottander & Grelsson, 2006). Besides, students understand abstract concepts deeply through laboratory activities because they are engaged in practical activities that involve data collection, analysis, and forming judgments. Therefore, through laboratory, practical activities, students can plan investigations, use scientific reasoning, manipulate equipment, record data, analyze, present, and discuss their results, and come up with conclusions (National Science Teachers Association, 2007). Moreover, laboratory experiments can facilitate fruitful learning by forming a connection between the newly discovered information and the existing information (Ambusaidi et al., 2018). Thus, it improves students' understanding of scientific concepts.

Besides, laboratory practical has great importance in science teaching and learning, the implementation of laboratory practical activities encountered the problems of inadequate teacher preparation, inadequate implementation of the procedure, lack of school laboratories, short supply of laboratory equipment, space constraints, overcrowded classrooms, dangerous experiments, and teaching and learning materials that are expensive to purchase and to maintain (Ndayambaje et al., 2021, Cossa & Uamusse, 2015, Miyamoto et al., 2019). In addition, some laboratory experiments can put the students in danger when involving the use of chemicals, and some accidents like burning, electrical shock, and infection, might occur (Muhamad et al., 2012). Consequently, Biology subject taught by using the traditional method of teaching as opposed to inquiry and innovative activity-oriented where the teachers direct students to learn abstract concepts through memorization of facts that lead to students' poor conceptual understanding (Ndayambaje et al., 2021 & Sibomana et al., 2021).

Therefore, in line with the advancement of technology to advance education, the introduction of information, communication, and technology such as virtual learning, simulation, animation, and video in education was taken into account to find an appropriate alternative way for effective science teaching and learning, to improve students understanding (Suryanti et al., 2019, Tatli & Ayas, 2010 & Ambusaidi et al., 2018). In this regard, Tüysüz (2010) noted that computer-based learning via virtual laboratory was one alternative practical tool for effective scientific learning. A virtual laboratory is defined as a computer-based activity in which students use a computer interface to interact with an experimental apparatus or other activity (Hatherly, 2009). Moreover, virtual laboratory is an interactive simulation that allows the students to conduct scientific experiments that are not currently available in a real laboratory with low cost and safety (Ambusaidi et al., 2018).

Virtual reality technology has brought fresh insights to support and improve the quality of education by demonstrating scientific phenomena to students without using actual resources. For instance, in European countries like Denmark, virtual laboratory is designed with computer software with experimental simulations under control, to allow the user to conduct scientific investigations cheaply, with a high level of safety, and more time-efficient than traditional laboratories (Suryanti et al., 2018). Also, in the United States of America(USA) virtual laboratory was designed for enhancing students' learning and motivation in order to achieve learning objectives (Swan & Donnell, 2009).

Various experiment simulations are created as tools or media to enhance the understanding of scientific concepts (Suryanti et al., 2019). This is because, virtual laboratory allows students to make mistakes with no repercussions compared to a real laboratory (Hamed & Aljanazrah, 2020). For instance, in Botswana virtual laboratory was used in teaching and learning to eliminate the constraints of real laboratories such as the time taken to set up the equipment, high-cost equipment, and level of safety, accuracy, and reliability of outcomes (Pearson & Kudzai, 2015). Additionally, Yamada et al. (2006) showed that virtual lab produces detailed images of human embryos and visualizes the sequential morphogenetic movements occurring in the embryo. For that reason, technologies in education by using computer-based instruction via virtual laboratories enhance science learning and support physical laboratories in order to concretize and clarify the concept.

Numerous researchers such as Muhamad et al. (2012), Hamed, and Aljanazrah. (2020), Ambusaidi et al. (2018), Suryanti et al. (2019), and Tatli and Ayas. (2010), focused on the effects of using virtual laboratories as a supplementary tool to physical lab in science subjects in general. Therefore, this study investigated the effects of virtual laboratories on the student's conceptual understanding of the foetal developmental process within the secondary schools of Rwamagana district as this instructional strategy had just implemented in this district as opposed to the previously-used typical lecture teaching strategy. The study was guided by the following questions:

1) Is there statistical differences in pre-test scores between students who learned foetal developmental process using virtual laboratory instruction and those who learned it through lecture-based traditional teaching methods?
2) Is there a statistical difference in post-test scores between students who learned foetal developmental process using virtual laboratory instruction and those who learned it through lecture-based traditional teaching methods?

2. Literature Review

The key goals of Rwanda's education system are to promote equitable access to education, and quality of learning, and to provide citizens with the skills and knowledge essential for the country's socio-economic development (MINEDUC, 2018). Achieving such goals, advanced technology, and the use of the computer as recent advancement in technology, across all levels of education is a logical way (Mugiraneza, 2021). Presently, computer-based learning has been used in education to achieve numerous purposes and the role of virtual-based learning is becoming more effective in teaching and learning.

2.1 Understanding virtual laboratory

The description of the virtual laboratory depends on how different people may perceive it and how it has affected teaching and learning for various target groups. A virtual laboratory is defined as the use of computer simulations, models, and a range of other learning technologies to support real laboratories (Scheckler, 2003). In a similar way, virtual laboratory is an interactive experiment simulation in which all manipulations are performed on a computer (Suryanti et al., 2019). It was further explained by Udin et al. (2020) as a simulation and animation lab that uses virtual technology to provide students with an interactive virtual learning environment. Therefore, in the present study, a virtual laboratory is understood as an interactive environment for designing and carrying out computer-simulated experiments that accurately represent the real world.

2.2 The effect of using virtual laboratory on students' conceptual understanding of biology

Effective and meaningful learning in science takes place if the students relate what they are learning with everyday life experiences. For that reason, laboratory experiments are an important component of learning science subjects, biology included. This view is supported by Muhamad et al. (2012) who stated that laboratory instruction is an important component for learning and understanding abstract scientific concepts. However, all scientific experiments cannot be carried out in a real laboratory, for example, cell structure and cell organization, cell division, the chemical composition of cells, and the foetal development process. Therefore, computer-based learning via virtual laboratory supports science learning to overcome limitations associated with physical laboratory (Dyrberg et al., 2017). Since, the use of computer-based learning in teaching and learning sciences, including biology becomes popular and has been continuously adapted in various fields of education (Hlásná et al., 2017).

Human embryo development undergoes complicated morphological changes. for the students to fully understand and analyze such dynamic movements visualizing embryonic structures supported by computer-assisted is essential. In this regard, the virtual laboratory has more benefits in teaching and learning sciences, and their effect has been reported by numerous scholars such as (Swan & O'Donnell., 2009, Flowers, 2011, Muhamad et al., 2012 & Dyrberg et al., 2017). For instance, In Jordan, the study conducted by Alfalah (2020) showed that virtual laboratory is the most effective approach for teaching embryology that helps students to visualize complex structures and their dynamic evolution. Alfalah's study also showed that virtual laboratory enhances the student's conceptual understanding, satisfaction, and learning outcome. Within the same line, in the study conducted by Swan & O'Donnell (2009) and Flowers (2011) in the United States of America on the contribution of virtual biology laboratories, the analysis of the findings revealed that conceptual understanding of the students that went through the virtual experiments performed better than the students taught by traditional lecture teaching method.

A virtual laboratory is highly suitable for teaching abstract biology topics which are complex for the student to fully understand the phenomena. This viewpoint is backed up by the study conducted in Japan by Widiyatmoko (2018) on the effectiveness of simulation on conceptual understanding of science subjects. The author used an integrative review of the literature by reviewing published

papers on the effectiveness of virtual labs in science learning. The researcher's findings indicated that virtual laboratory allows learners to observe a real-world experience, and they can interact with it. In general, concepts that are difficult for students to grasp can be understood experimentally in science learning, particularly in biology. This is supported by the study conducted in New Zealand and Indonesia by Dyrberg et al. (2017), Suryanti et al. (2019), and Azizah and Aloysius (2020). The authors used a quasi-experimental approach to compare the learners who were involved in virtual experiments and the participants in traditional instruction. The findings showed that the students who participated in virtual laboratory instruction performed better compared to students who only had a "chalk and talk" experience. Thus, the usage of a virtual laboratory allows students to broaden their experiences and enhance students critical thinking as well as conceptual understanding of different scientific concepts.

A study was conducted in Zimbabwe and Botswana, by Nelson (2020) and Hamed and Aljanazrah. (2020) on the effective use of virtual labs in teaching biology which revealed that the effective use of virtual laboratory activities had a positive impact on students' academic achievements and attitudes toward biology, compared to traditional methods. On the other hand, a study conducted in Kenya by Mochama et al. (2020) revealed that the conceptual understanding of the students in the experimental group performed better than that of the control group at $t_{cal} = 2.019$; $df = 50$, $p = 0.049$. Another study conducted in Rwanda on the effectiveness of Virtual Laboratories in teaching and learning biology by Byukusenge et al. (2022) revealed that effective use of virtual laboratories improves students' conceptual understanding, laboratory or practical skills, and motivation and attitudes toward biology. Therefore, using a virtual laboratory in science instruction is suitable and convenient, especially when it is appropriately utilized.

In this study, numerous researchers have emphasized the effect of virtual laboratories on the student's conceptual understanding of biology in general and other sciences subjects. However, in Rwanda, no research has been conducted on the effect of virtual laboratories to enhance students' understanding of foetal developmental process. Therefore, it is on that weakness this study wishes to investigate the effect of virtual laboratory on students' conceptual understanding of biology concepts, particularly foetal development process.

2.3 Theoretical Framework

This study was guided by the constructivism theory of learning, which holds that knowledge is actively constructed by the learner and not passively transmitted by the teacher. This theory deals with the involvement of the students in intelligent action, and social interaction with themselves and with the teacher in practical activities and the tools that help them to construct their knowledge (Olusegun, 2015). Based on this theory, a deep understanding of abstract scientific concepts occurs when the students are actively engaged in the process of knowledge acquisition by linking new ideas to previous knowledge (Koretsky et al., 2008). Thus, contents delivered by computer assistance technology extend students' ability to understand abstract concepts and achieve learning objectives.

This theory is compatible with this study because of the use of virtual laboratories in teaching and learning human development students, engaged in virtual experiments through the provision of animation, video, and audio content. In addition, virtual laboratory allows the learners to construct their knowledge and relate new knowledge to previous knowledge in meaningful ways (Amineh & Asl, 2015). Therefore, teachers act as facilitators and ensure that the learners are active participants in virtual experiments to achieve learning objectives.

3. Methodology

3.1 Research Design

The main objective of this study was to investigate the effects of virtual laboratories on the student's conceptual understanding of the foetal developmental process. The quasi-experimental design was adapted to explain the variation of data under hypothesized conditions (Cohen et al., 2007 & Creswell, 2014). Thus, Pre- and post-tests were utilized in this study to measure the effect of virtual laboratory on students' conceptual understanding foetal development process.

3.2 Population and sampling

In this study, the population consists of all senior one students in Rwamagana district. As human development is a subject introduced in senior one, the researcher used senior one classes. From the population, four schools were purposively selected, based on the availability of the internet, computers, projectors, and smart classrooms. The four schools were randomly split into a control group composed of 81 students and an experimental group composed of 81 students. The experimental group learned through virtual laboratory instruction while the control group learned through the traditional teaching approach.

3.3 Instruments

The biology achievement test was constructed by the researcher based on the competencies and learning objectives highlighted in the senior one biology book and syllabus. The biology achievement test was made of multiple-choice questions. The data collection instruments in form of a biology achievement test were used to measure the students' conceptual understanding of foetal development of control and experimental group prior to the intervention. The students from the experimental group were taught via virtual experiments and control group was taught with the traditional teacher-centered method. After the intervention, the post-test was given to both control and experimental group to measure the effect of virtual laboratory on students' conceptual understanding of foetal development.

3.4 Validity and reliability

To ensure the reliability and validity of the instruments, the supervisor and two biology educational experts from University of Rwanda, College of Education, validate the instruments before their use. This was done to make sure that the test's face and content were valid. In this study also the pilot study under test-retest reliability was used to analyze the feasibility and relevance of the instruments. The small group of students from two schools apart from four schools under the study who used the virtual laboratory in learning biology (experimental group) and a small group who was taught theoretically were given a pre-test before intervention. After, the students were given a post-test twice over a period. The Pearson correlation coefficient(r) was used to correlate the obtained scores from the first time and the second. Thus, Pearson correlation coefficient (r) was equal to 0.74, which is considered as acceptable for an instrument to be reliable. This assured that the tools were appropriate for collecting trustworthy data.

3.5 Ethical consideration

Before collecting the data, the researchers obtained ethical clearance from the Director of Research and Innovation at the University of Rwanda College of Education. Also, before we collected data from the field we wrote a research authorization letter to the Mayor of Rwamagana District requesting to conduct research in his district. The permission letter was obtained and the Mayor wrote a letter that introduced a researcher to the four sector coordinators and school head teachers. Later, the permission to work was guaranteed by sectors 'coordinators and school head teachers. Therefore, this study valued the ethical issues and dignity of all participants, and the names of the schools and students were not mentioned.

3.6 Data analysis

The collected data from the pre and post-test were analyzed by using SPSS statistical package version 25. Means and standard deviations for achievement tests were analyzed by using descriptive statistics and a t-test to determine whether there is a significant difference between the two means for each test, before and after the intervention. The t-test was pre-determined at α=0.05 significance level to reject or accept the null hypotheses.

4. Results and Discussion

The results were presented as guided by the research questions.

Q1. Is there a statistical difference in pre-test scores between students who learned foetal developmental process using virtual laboratory instruction and those who learned it through lecture-based traditional teaching methods?

To measure the impact of a virtual laboratory on the students 'conceptual understanding of the foetal developmental process, the experimental and control groups were administered pre- and post-test biology achievement tests to compare the mean scores differences of students before and after using virtual laboratory in learning.

Table1: Pre-test scores analysis by using descriptive and inferential statistical test

	Group	N	Mean	Std.Deviation	T	Df	Sig.(2tailed)
Pre-test score	Experimental	81	13.95	3.660	0.566	160	0.573
	Control	81	14.32	4.620			

T-value significant at $p < 0.05$.

The findings of table 1 present the mean score of the control group and experimental group, with [t (160) = 0.565515, p = 0.572516; p>.05]. This informs that the mean score of the control and experimental group was approximately the same. Therefore, we fail to reject the null hypothesis which means that there was no statistical variation in the mean score of the control and experimental group. Thus, the results indicate that the student's conceptual understanding and their characteristics are at the same standard for the study. Hence the students' conceptual understanding before the use of VL in teaching and learning was the same.

Q2. Is there a statistical difference in post-test scores between students who learned foetal developmental process using virtual laboratory instruction and those who learned it through lecture-based traditional teaching methods?

In this study, the students in the control group were taught by the traditional teaching approach (chalk-talk approach), while those in the experimental group were taught using VL in their learning. After instruction, a posttest was administered to the students in both groups to examine whether there is a statistical difference in conceptual understanding based on the scores they obtained.

Table 2: Post-test scores analysis by using descriptive and inferential statistical test

	Group	N	Mean	Std.Deviation	T	Df	Sig.(2tailed)
Post-test score	Control	81	14.02	5.408	-0.540	160	0.000
	Experimental	81	18.30	4.349			

T-value significant at $p < 0.05$.

Table 2 represents the result of the post-test. The findings indicated that the students in the experimental group and control group performed differently with [t (160) = -.540, p = 0.000; p<.05]. This showed that virtual laboratories have a greater effect on students' conceptual understanding than traditional teaching methods. In the same context, these findings indicate that students in the experimental group who went through virtual laboratory performance level and understanding of the concepts related to the foetal developmental process were more.

Since the P-value was equal to 0.000 and was less than the significant level of 0.05, Therefore, we reject the null hypothesis (HO) which states that there is no significant difference in the mean score achievement of the students taught the foetal developmental process by using virtual laboratory and those who taught by traditional methods. This means that there is a significant difference in the students' conceptual understanding when students learned using virtual laboratory and students learned with traditional lecture methods.

Discussion

This study was to investigate the effect of virtual laboratory on the student's conceptual understanding of the biological concept. Our focus topic was foetal development process. The researcher administered the test to both control and experimental groups to check whether the virtual laboratory affects the student's conceptual understanding or not. As indicated in Table 2 the post-test result obtained from the experimental group are higher than the result from the control group. Therefore, there is a significant difference in the students' conceptual understanding between students who learned by utilizing virtual laboratories and students who learned with traditional lecture methods. Then, this study showed that using virtual laboratories in teaching and learning biology improves the student's conceptual understanding more than traditional lecturing methods.

The findings are in line with that of Suryanti et al. (2019) who investigated the impact of virtual laboratories as media to improve students' conceptual understanding of molecular biology. Their finding of post-test results showed that the students involved in virtual experiments conceptual understanding was higher. This is because students taught in virtual laboratories are actively participating in the teaching and learning process, which enhanced their conceptual understanding. This is also supported by the constructivist learning theory guiding this study, whereby the students understand deep abstract scientific concepts when they are actively engaged in the process of knowledge acquisition by linking theory with new life situations (Koretsky et al., 2008). Moreover, virtual laboratory increases students' motivation and interest, enhancing critical thinking and problem-solving skills (Flowers, 2011). Hence, virtual learning environment

by using animation and simulation for the abstract topic, where the students are actively engaged in the learning process, provides the students with opportunities to understand abstract concepts more easily.

In the same context, the studies by Swan and Donnell (2009), Herga and Dinevski (2012), and Muhamad et al. (2012) investigated the contribution of a virtual laboratory and they found that the students who learned contents in class using a virtual laboratory level of conceptual understanding in term of score obtained were better than the students in the control group. Therefore, a virtual laboratory, when used effectively, has a positive impact on the student's conceptual understanding of sciences subjects including biology. Additionally, the findings agreed with Udin et al. (2022), who revealed that a virtual laboratory is an alternative way of lesson delivery that improves students' conceptual understanding of complex biological contents. In this regard, effective use of virtual laboratories involves fundamental concepts that promote coherent conceptual understanding and connection with real-world phenomena. This offers the students to do experiments, collect data, and prepare reports for experiments with developing experimental skills.

This study also showed that the students validate their prior knowledge in a virtual laboratory and generate new ideas on the foetal development process via manipulation of the virtual experiment. This view is supported by Muhamad et al. (2012) who showed that the use of virtual lab-based learning to conduct scientific experiments enables the students' deeper understanding of the topic they learned in a more meaningful manner by linking what they already know with new knowledge. Virtual laboratory leads students to find and carry out investigations so that the learning process becomes more meaningful (Azizah &Aloysius, 2020). Thus, all those activities involved in the virtual experiment have a significant influence on the student's conceptual understanding.

The use of virtual laboratories has a positive influence on students' conceptual understanding of abstract biology concepts as revealed by the study findings. This agrees with the results of research conducted by Ramadhan and Irwanto (2017) showed that the use of virtual laboratories in learning has a positive influence on students' understanding. This is because virtual laboratory enhances students 'creativity, critical thinking, motivation, and learning outcome. In the same context, the study conducted by Zaturrahmi et al. (2020) and Faour and Ayoubi (2018) showed that the usage of virtual laboratories in the classroom has increased the learning process' effectiveness and efficiency while also enhancing the students 'understanding and learning achievement. Thus, virtual laboratory improves the students 'conceptual understanding and independent learning.

Our focus in this investigation was to determine whether there was a difference between students taught using the virtual laboratory instructions and those taught using the conventional lecture teaching approach in terms of the mean score on students' conceptual understanding of foetal developmental process topic, in biology subject. The findings of this study revealed that when the virtual laboratory is used effectively, it has a significant influence on the student's conceptual understanding. This is because virtual experiment provides students with interest, intention, motivation, and collaboration by sharing ideas and reflecting on what they are observing.

5. Conclusion and recommendations

5.1 Conclusions

The objective of the present study was to investigate the effect of virtual laboratories on the student's conceptual understanding of biology. This was achieved by comparing the mean-score achievements of senior one students who were taught foetal developmental stages under virtual laboratory experiments and those who were taught the same concept by the traditional lecturing method (chalk-talk method). The pre and post-test biology achievement tests were administered to both the control and experimental group. The findings revealed that virtual laboratory experiment has a more significant influence on students' conceptual understanding of biology than traditional teaching method.

5.2 Recommendations

Based on the findings, this study recommends teachers strive to use virtual laboratories in teaching biology as an alternative way of improving students' conceptual understanding. Virtual laboratory practice should also be a frontline and fundamental instructional method for biology teaching, and other science subjects like chemistry and physic should also adopt it. Students should take virtual laboratories as a vital method for learning biology in particular. This also recommends further researchers to explore the effect of virtual laboratories on the student's conceptual understanding of other biology topics that are difficult for the students to understand. Since this study was carried out only on senior one students, further research can be conducted to examine the effects of virtual laboratories on students' conceptual understanding of biology at other educational levels.

References

Ambusaidi, A. Musawi, A.A., Balushi, S.A., Balushi, K.A. (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: 10.12973/tused.10227a

Alfalah, S. (2020). The Value of virtual reality technology in embryology education; Objective and subjective outcomes. *International Journal of Psychosocial Rehabilitation, 24*(9), 4672-4684. https://doi: 10.37200/IJPR/V24I1/PR2904898

Amineh, R.J., Asl,H.D. (2015). Review of constructivism and social constructivism. *Journal of Social Sciences, Literature, and Languages, 1*(1), 9-16.

Awosika, I. (2008). The contributions of biological science to national development: Nigerian experience. *Ife Journal of Science, 10* (1), 97-101.

Azizah, N., Aloysius, S. (2020). The effects of virtual laboratory on biology learning achievement: A literature review. *Advances in Social Science, Education and Humanities Research, 541*(1), 107-116.

Byukusenge, C., Nsanganwimana, F., Tarmo, A.P. (2022). Effectiveness of virtual laboratories in teaching and learning biology: A review of literature. *International Journal of Learning, Teaching and Educational Research, 21*(6), 1-17. https://doi.org/10.26803/ijlter.21.6.1

Cohen, L., Manion,l., Morrison,k. (2007). Research methods in education (6th ed.).

Cossa, E.F.R., Uamusse,A.A. (2015). Effects of an in-service program on biology and chemistry teachers' perception of the role of laboratory work. *Procedia - Social and Behavioral Sciences, 167* (1), 152-160.

Creswell, J. W. (2014). Research design: Quantitative, qualitative, and mixed methods approach. (Fourth, Ed.) London, Inc: SAGE Publication.

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), 351-378. https://doi: 10.1080/00219266.2016.1257498.

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.

Education Sector Strategical Plan. (2018). Education sector strategic plan 2018/19 to 2023/24. Kigali.

Flowers, L.O. (2011). Investigating the effectiveness of virtual laboratories in an undergraduate biology course. *The Journal of Human Resource and Adult Learning, 7*(2), 110-116.

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

Guo, J. (2018). Application of virtual laboratory in biology teaching. *International Conference on Education, Management and Information Technology, 2*(1), 341-345

Hamed G., & Aljanazrah, A. (2020). The effectiveness of using virtual experiments on students learning general physics lab. *Journal of Information Technology Education: Research, 19*(1), 976-995.

Hatherly, P. A., Jordan, S. E., & Cayless, A. (2009). The virtual laboratory and interactive screen experiments. *European Journal of Physics, 30*(4), 751–762.

Herga, N.R., Dinevski, D. (2012). Virtual laboratory in chemistry –experimental study of understanding, reproduction, and application of acquired knowledge of subject's chemical content. *Organizacija, 45*(1),108-116. https://doi: 10.2478/v10051-012-0011-7

Hlásná, P., Klímová, B. (2017). Use of information and communication technologies in primary education – A Case Study of the Czech Republic. *International Electronic Journal of Elementary Education, 9*(3), 681-692.

Koretsky, M.D., Amatore,D., Barnes,C., Kimura,K. (2008). Enhancement of student learning in experimental design using a virtual laboratory. *IEEE, Transactions on Education, 51*(1), 76-85.

Ministry of Education. (2018). Education Sector Strategic Plan 2018/19 TO 2023/24. Kigali.

Miyamoto, M., Milkowski, D.M., Young,C.D., Lebowicz,L.A. (2019). Developing a virtual lab to teach essential biology laboratory techniques. *Journal of Biocommunication, 43*(1), 23-31.

Mochama, O. E.., Obuba, E. M., & Omwenga, E. (2020). Influence of virtual laboratories on academic

achievements in Physics: The case of tertiary education in Kenya. *Journal of Education, Curriculum and, 1*(2), 1-19.

Mugiraneza, J. P. (2021). Digitalization in teaching and education in Rwanda. International Labour Organization.The report, 28

Muhamad, M., Zaman, H. B., & Ahmad, A. (2012). Virtual biology laboratory (VLab-Bio): scenario-based learning approach. *International Conference on Education and Educational Psychology, 69* (1), 162 – 168.

National Science Teachers Association. (2007). A positional statement: The integral role of laboratory investigations in science instruction.

Ndayambaje, J.B., Bikorimana, E.,Nsanganwimana, F. (2021). Factors contributing to the student's poor performance in biology subject: A case study of ordinary level in rural secondary schools of Rwamagana district. *GSC Biological and Pharmaceutical Sciences, 15*(3), 249–261.

Ndihokubwayo, k., Habiyaremye, T.H . (2018, September). Why did Rwanda shift from knowledge to competence based curriculum? Syllabuses and textbooks point of view. *African Research Review, 12* (3),38-48. DOI: http://dx.doi.org/10.4314/afrrev.v12i3.4

Ndihokubwayo, K., Ndayambaje, I., Uwamahoro, j . (2019). An assessment of the impact of improvised versus conventional laboratory equipment on students' performance in Thermal Expansion. *African Journal of Educational Studies in Mathematics and Sciences, 15*(1), 135-140.

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.

Nelson, V. (2020). Effective use of virtual labs in the teaching of ordinary-level biology concepts in Insiza district, Matebelel and south province. [Unpublished thesis submitted in partial fulfillment of the requirement of degree of master of education] University of Bandu.

Olusegun, S.D. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education, 5*(6), 66-77.

Ottander, S., Grelsson, G. (2006). Laboratory work: The teachers' perspective. *Journal of Biological Education, 40*(3), 113-118.

Ramadhan, M.F., and Irwanto. (2017). Using virtual labs to enhance students' thinking abilities, skills, and scientific attitudes. *International Conference on Educational Research and Innovation*,*3*(5), 494-499.

REB. (2015). Ordinary level biology syllabus (S1-3). Kigali.

Pearson, C., & Kudzai, C. (2015). virtual laboratories- a solution for tertiary science education in Botswana? *European Journal of Logistics Purchasing and Supply Chain Management, 3*(1), 29-43.

Scheckler, R. K. (2003). Virtual labs: a substitute for traditional labs? *International Journal of Developmental Biology, 47*(2), 231-236.

Sibomana, A., Nicol,C.B., Nzabalirwa,W., Nsanganwimana,F., Karegeya,J.C. (2021). Factors affecting the achievement of twelve-year basic students in mathematics and science in Rwanda. *International Journal of Learning, Teaching and Educational Research, 20*(7), 61-84.

Suryanti, E, Fitriani A , Redjeki S , Riandi, R. (2018). Virtual laboratory as a media to improve the conceptual mastery of molecular biology. *IOP Conf. Series: Journal of Physics: Conf. Series, 1317* (1), 012202. https://doi:10.1088/1742-6596/1317/1/012202

Swan, A. E., & O'Donnell, A. M. (2009). The contribution of a virtual biology laboratory to college students learning. *Innovations in Education and Teaching International, 46*(4), 405–419.

Tatli, Z., Ayas, A. (2010). Virtual laboratory applications in chemistry education. *Procedia Social and Behavioral Sciences, 9* (1), 938–942. https://doi:10.1016/j.sbspro.2010.12.263

Tuysuz, C. (2010). The Effect of the virtual laboratory on students' achievement and attitude in chemistry. i*nternational Online Journal of Educational Sciences, 2* (1), 37-53.

Udin,W.N., Ramli, M., Muzzazinah . (2020). Virtual laboratory for enhancing students' understanding on abstract biology concepts and laboratory skills: a systematic review. *Journal of Physics:*

Conference Series, 1521 (4), 042025. https://doi:10.1088/1742-6596/1521/4/042025

Widiyatmoko, A. (2018). The effectiveness of simulation in science learning on conceptual understanding: A Literature Review. *Journal of International Development and Cooperation, 24*(1), 35-43.

Yamada, S., Uwabe, C., Nakatsu-Komatsu, T., Minekura, Y., Iwakura, M., Motoki, T., Nishimiya, K., Iiyama, M., Kakusho, K., Minoh, M., Mizuta, S., Matsuda, T., Matsuda, Y., Haishi, T., Kose, T., Fujii, S., & Shiota, K. (2006). Graphic and movie illustrations of human prenatal development and their application to embryological education based on the human embryo specimens in the Kyoto collection. *Developmental Dynamic, 235*(2), 468-477.

Zaturrahmi , Festiyed, and Ellizar. (2020). The utilization of virtual laboratory in learning: a meta-analysis. *Indonesian Journal of Science and Mathematics Education, 3*(2), 228-236.