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Effectiveness of virtual laboratory vs. paper-based experiences to the hands-on chemistry practical in Tanzanian secondary schools

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Abstract
Science subjects at pre-tertiary and tertiary education levels are important for socio-economic and industrial development of any country; however, they are difficult for students to construct their concepts. In Tanzania, insufficient or lack of practical experiments are major challenges for science subjects due to insufficient or lack of laboratories, apparatus, expertise or reagents. Thus, this research assesses the effectiveness of paper-based practical against virtual laboratory experiences towards improvement of real (hands-on) chemistry practical in Tanzanian secondary schools focusing in Dodoma region. Chemistry virtual laboratory was developed and being deployed at Dodoma Secondary School for students who were never done practical sessions before to avoid biasness towards the study. The students were divided into three groups, namely paper-based and real laboratory as control groups (CG) and virtual laboratory as the experimental group (EG). Each group was further divided into two groups for the rest approaches forming six (6) groups. For EG, students were taught based on instructional approach which was enriched by computer animations in the computer laboratory. Results indicate that students who firstly attended virtual laboratory performed better in real laboratory than those who firstly attended real laboratory. Furthermore, the best progressive learning and performance for real experiments appears when the virtual laboratory preceded paper-based practical experiments. Thus, virtual laboratory is a very useful tool for learning chemistry practical not only to schools without laboratories but also to those with laboratories; and it should be considered by all pre-tertiary schools in Tanzania and other schools in similar situations.

Keywords Virtual laboratory · Paper-based experience · Hands-on practical · Chemistry practical · Chemistry · Tanzania

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1 Introduction

In pre-tertiary education levels, practical sessions on science subjects are mandatory and efficient procedures in science education. Studies show that these practical sessions significantly increase students' learning effectiveness and performance in Science, Technology, Engineering and Mathematics (STEM) courses more than traditional lecture-style teaching (Baragona, 2009; Freeman et al., 2014; Morell, 1994). Moreover, these practical sessions enhance students' interests in the subject matters (Halim et al., 2018; Jones & Stapleton, 2017) and support the students through future STEM careers in tertiary education levels. Research in chemistry practical by Reid and Shah (2007) indicates that the practical laboratory activities enable students to generate four skills including skills related to learning chemistry, practical skills, scientific skills and general skills. Thus, Seery (2020) concluded that chemistry practical laboratory is the place to learn how to do chemistry.

The Tanzanian pre-tertiary education levels operate competence-based chemistry syllabus which insists on students to experience and carry out hands-on laboratory exercises (Ministry of Education and Vocational Training [MoEVT], 2007, p. 1). The Certificate of Secondary Education Examination (CSEE) in chemistry involves Theory paper, Actual (Hands-on) practical paper and Alternative (Paper-based) practical. However, laboratory applications in different developing countries like Tanzania face different challenges including cost of implementation and running of the existing laboratories. In addition to construction of physical laboratory infrastructure, implementation and running costs; physical laboratory sessions demand directly personnel involvement and time consuming (Bretz, 2019; Reid & Shah, 2007) which is tricky during pandemic lockdown like that of Covid-19. Furthermore, reagents are currently very expensive (Hofstein & Lunetta, 2004; Durmus & Bayraktar, 2010) and the number of students increases linearly with increase of the number of years (Mkimbili et al., 2017; Luvanga & Mkimbili, 2020). Such increase of number of students is due to success of the education policy in Tanzania which demands every ward to have secondary schools as by now on average every ward in Tanzania has at least one secondary school. The key and important challenges to these ward schools are science laboratories particularly for chemistry. Chemistry laboratories are more expensive to implement in secondary schools because they require a lot of and more expensive reagents than other science subjects like physics and biology. Consequently, there is poor construction and development of chemistry concepts and calculations of practical related mathematics resulting to poor performance.

The weak performance in chemistry for the Tanzania Certificate of Secondary Education Examination (CSEE) is mainly attributed to poor performance in Actual practical paper and Alternative practical paper. Insufficient or lack of practical experiments are major challenges for chemistry due to insufficient or lack of laboratories, apparatus, expertise or reagents in the country. The report analysis of the performance of the candidates who sat for the Certificate of Secondary Education Examination (CSEE) during 2018, 2019 and 2020 in chemistry indicates poor performance in practical chemistry with particular some of the topics (https://

www.necta.go.tz/brn). In CSEE 2018, weak performance of candidates appeared in the topics of Mole Concept and Related Calculations as it was reported in CSEE 2017 results. The candidates in CSEE 2019 poorly performed the topics of Chemical Kinetics, Equilibrium and Energetics, The Mole Concept and Related Calculations, Pollution and Non-metals and Their Compounds. In CSEE 2020, Volumetric Analysis topic had average performance while weak performance was in Chemical Equations (27.1%), Water (26.1%), Laboratory Techniques and Safety (22.1%), and Ionic Theory and Electrolysis (13.0%). The weak performance in these topics stated above linked with inadequate knowledge of the candidates about the tested concepts, failure to identify the requirements of the respective questions, poor English language proficiency and lack of adequate mathematical skills. Such poor performance affects the enrollment at tertiary education levels for the STEM education status in the country resulting to a small fraction of the world's scientific research and publication output rate from Tanzania and Africa as chemistry is a major bridging subject in many STEM careers and professionals.

A well-designed virtual laboratory can provide students with meaningful virtual experiences and present important concepts, principles, and processes (Tatli & Ayas, 2013; Kapici et al., 2019, 2020; Tugtekin & Dursun, 2022) particularly for the STEM subjects. Comparing to hands-on laboratories, virtual laboratory experiences provide flexibility of self-learning with greater accessibility in safe environment by saving time and costs (Alkhaldi et al., 2016; Faulconer & Gruss, 2018; Ali & Ullah, 2020). By means of virtual laboratories, students have the opportunity of repeating any incorrect experiments as well as to deepen the intended experiences. Moreover, the interactive nature of such teaching methods which most of them are multimedia and simulations (Bellou et al., 2018) offers a clear and enjoyable learning environment (Ardac & Akaygun, 2004; Jeschke et al., 2010; Caprara & Caprara, 2022; Leitão et al., 2022). As a result, virtual laboratories are not only used as a substitute to real laboratory but they can also be used to supplement the hands-on laboratory and provide effective and rapid learning outcomes in the respective STEM subjects or courses (Abdulwahed & Nagy, 2009).

Alexiou et al. (2004) presented a virtual laboratory called Virtual Radiophamacy Laboratory aimed at facilitating secondary schools in Greece to foster their science learning in chemistry and physics. The virtual laboratory developed was a web-based virtual laboratory, which apart from complementing practical learning processes and science actions, it provides communication, and collaboration services (Alexiou et al., 2004). Tüysüz (2010) researched on the effect of the virtual laboratory on students' achievement and attitude in chemistry as attitudinal improvement between real (hands-on), virtual, or combinations of these labs as revealed by Kapici et al. (2020). In the study by Tüysüz (2010), a virtual laboratory related to "Separation of Matter" unit for 9th grade students in Turkey was prepared and its effects on students' achievements and attitudes were investigated. The study concluded that there was a significant improvement in students' performance in a particular unit, students' motivation towards respective unit/subject and students' ability to recognize laboratory equipment (Tatli & Ayas, 2013). Basing on Virtual Reality (VR), Hu-Au and Okita (2021) reported improved students' learning results and safety behaviour for general content knowledge and procedures related to safety behaviour in comparable with Real Life (RL). The virtual laboratory approach tends to have similar or better results than traditional methods for secondary education with most effective results when it is combined with real or hands-on laboratory or blended approach (Sypsas & Kalles, 2018; Chan et al., 2021). Moreover, the out-performance of simulated learning approach appeared against experiential learning in improving students' conceptual understanding of the integration of motion along independent axes in projectile motion (Chinaka, 2021). Thus, virtual laboratory for chemistry can save time and costs for constructions of physical laboratory infrastructures and buying reagents as well as implementation and running of the physical laboratories. Apart from supplementing present scarcity of physical laboratory facilities and personnel, chemistry virtual laboratory removes the demands of physical presence of teachers and students during practical sessions. Thus, virtual laboratory enables practical experiences even during pandemic lockdown events like that of Covid-19 with much flexibility when online infrastructure and facilities are available (Ulum, 2022).

However, little has been done on virtual laboratory for secondary schools in Tanzania in order to improve learning of STEM subjects and particularly chemistry. Thus, this research targets to assess effectiveness of the developed virtual laboratory in chemistry against paper-based experiences towards improvement of real (hands-on) chemistry practical in Tanzania. The research specifically addresses the following research questions:

i What is performance of real (hands-on) experiments in Tanzanian secondary schools for challenging chemistry topics for novice students?

ii How does the experiences in virtual laboratory against paper-based improve learning and performance of real (hands-on) experiments in Tanzanian secondary schools for challenging chemistry topics?

2 Theoretical framework

The social constructivism view of learning (Vygotsky, 1978) is considered in this study in order to observe knowledge construction that occurs best within environments in support of virtual laboratory or paper-based experiences towards real (hands-on) chemistry practical. Generally, the theoretical view supports that learning occurs within a social interaction with other students as a crucial component of the learning process. Furthermore, the constructed knowledge of a student can be developed to a certain level and grow further after interaction with different supporting tools, fellow students or teachers in different environments (Green & Gredler, 2002).

In order to understand construction and growth of knowledge of students towards chemistry practical, students were divided into three groups and being exposed to paper-based laboratory, real (hands-on) laboratory or virtual laboratory. In the arm of paper-based laboratory, students were taught by using chalk and talk method as commonly known as traditional method, assuming that there is neither a chemistry laboratory nor any equipment in the school. The second control group of real practical laboratory, the instructor taught the same materials but with demonstration of real equipment. To the experimental group (virtual laboratory) students were taught based on instructional approach, which was enriched by computer animations at the computer laboratory. Each group was divided into further two groups and then being exposed to the both rest of approaches. At the end of the instructional sessions of all groups, generated knowledge and attitude towards chemistry were tested focusing to hands-on chemistry. The focus is to observe constructed ideas can be easily transferable to other environments like from virtual laboratory or paper-based to real (hands-on) laboratory experiments (Mascolo & Fischer, 2015).

3 Significance of the study

The study is important to anyone who teaches and/or learns chemistry with or without the possibility of real laboratories and have the information and communications technology (ICT) tools. Apart from supplementing present scarcity of physical laboratory facilities and personnel, chemistry virtual laboratory removes the demands of physical presence of teachers and students during practical sessions; and thus, enables practical experiences even during pandemic lockdown events like that of Covid-19.

Furthermore, the research supports different goals and visions from international to country levels. It contributes to multiple United Nations Sustainable Development Goals (SDGs) (United Nations General Assembly 2015) including the following: Goal #4 on quality education to which the study targets to support quality education as a main key to alleviate poverty (Goal #1), improve health and well-being (Goal #3) and seeks to ensure inclusive and equitable quality education (Goal #5 and #10). For Goal #9 on industry, innovation and infrastructure, this study seeks to build strong science foundation at pre-tertiary education levels which provide students for tertiary education levels. Moreover, the study aligns with the African 2063 Agenda adopted by the African Union (AU), the East Africa Community Vision 2050 and the Tanzania Development Vision of 2025. All these agenda or visions mainly emphasize on well-educated citizens and skills revolution underpinned by Science, Technology and Innovation (STI).

Proper development and applications of virtual laboratories could help in planning and management of science subjects to improve practical experiences as well as STEM careers and professionals. Thus, the findings of this study add knowledge of virtual laboratory as well as to policymakers on proper utilization of technology for socio-economic development of the country during normal circumstances as well as during pandemic events like the recent one of Covid-19.

4 Methodology

The methodology of this study involves research design as well as experiment setting and procedures. Furthermore, the data analysis of the study is provided at the end of this section.

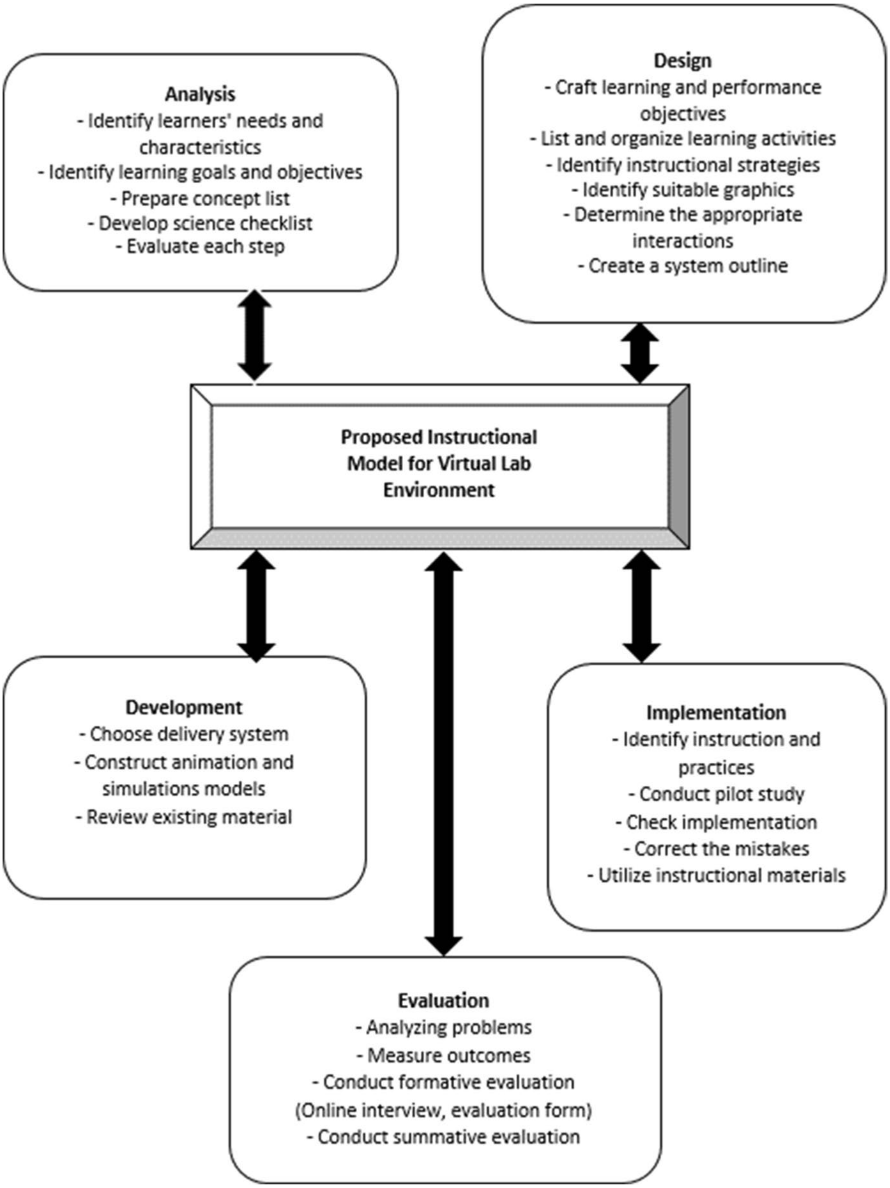

Fig. 1 The ADDIE model for the developed chemistry virtual lab environment

4.1 Research design

The research deployed instructional design model by adopting Analyzing, Designing, Developing, Implementing and Evaluating (ADDIE) model to develop chemistry virtual laboratory as depicted in Fig. 1. This model is the most basic and applicable model as a generic and systematic instructional systems design model (Reiser & Dempsey, 2007) which was successfully used by El-Sabagh (2011). The phases of the model are explained below:

4.1.1 Analysis

- Analyzing target group and their needs;
- Identifying challenging topics in chemistry for Tanzanian secondary schools;
- Identifying chemistry concepts, chemistry process skills checklist, and necessary activities;
- Developing objectives for the virtual laboratory for the selected topics;
- Selecting schools basing on availability of ICT infrastructure and/or physical laboratories;
- Identifying and establish need assessment for ICT awareness.

4.1.2 Designing

- Selecting and organizing the suitable hardware and software tools;
- Designing chemistry virtual laboratory architecture;
- Designing an assessment plan;
- Identifying and designing content types, forms and delivery;
- Creating detailed website outline;
- Determining the appropriate students' interactions with the contents.

4.1.3 Developing

- Developing the chemistry virtual laboratory according to chemistry virtual laboratory architecture of the website or stand-alone application;
- Developing contents;
- Developing systems using animation and simulation techniques;
- Getting feedback from experts of the selected topics;
- Conducting pilot experiments for some students.

4.1.4 Implementing

- Field test and evaluation;
- Preparation of delivery environment in terms of workshops and infrastructure for students and teachers;
- Deploy the chemistry virtual laboratory to the selected schools;
- Receive feedbacks and correct the mistakes;
- Testing the impacts of students towards chemistry topics;
- Experimental treatment: two trials will take place in order to evaluate the impact and usability of both the activities and the chemistry virtual laboratory.

4.1.5 Evaluation

- Analyzing systems' problems;
- Measure outcomes of the chemistry virtual laboratory;
- Conduct formative evaluation for the systems and students;
- Conduct summative evaluation for the systems and students.

The study focuses on developing a chemistry virtual laboratory for the topics of the Mole Concept and Related Calculations, Volumetric Analysis; and Laboratory Techniques and Safety, which appear to be performed averagely or weakly through the reports of CSEE from 2017 to 2020. Furthermore, a quasi-experimental research design was adopted from Campbell et al. (1963) with pre and post-tests, as well as experimental-control-group model. The study was carried out at Dodoma Secondary School in Dodoma region as the school which has availability of ICT infrastructure like computer laboratory and physical laboratory for hands-on chemistry practical. Basing on Information and Computer Studies (ICS) subject, there was easier to identify and establish ICT awareness and general chemistry knowledge through pre-testing.

4.2 Experiment setting and procedures

The experiment setting involved seventy-nine (79) students who were studying at Form Two level at Dodoma Secondary School in Dodoma region (Fig. 2). Dodoma Secondary School is the co-education/mixed sex school. The purpose of choosing the Form Two class was that, these students had never before studied or done practical sessions of the selected topics to avoid biasness towards the results. Before the intervention, the students sat for pre-tests of general information and communication technology (ICT) and chemistry. The purpose of these pre-tests was to explore existing awareness and knowledge among the participants in ICT and chemistry. Thereafter, the students were divided into three groups namely paper-based laboratory, real (hands-on) laboratory and virtual laboratory. The paper-based and real laboratory

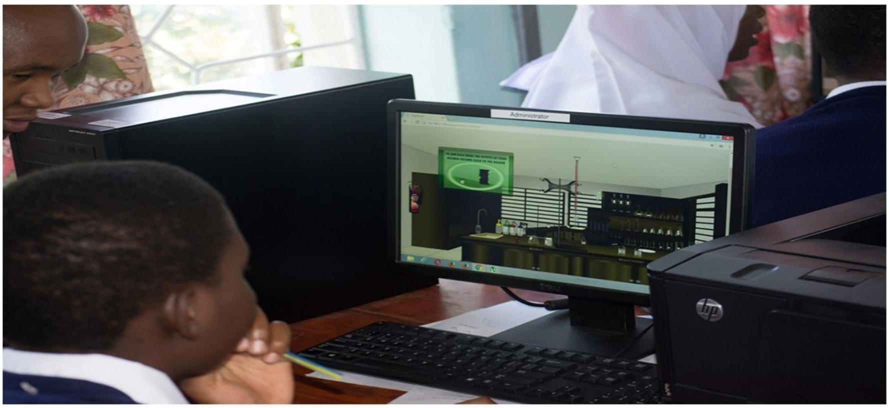

Fig. 2 A view action of a student at Dodoma Secondary School participating in virtual lab experiment

were treated as control groups (CG) while virtual laboratory was the experimental group (EG).

In those groups, teaching of the practical was introduced to each group. In the group of paper-based laboratory, students were taught by using chalk and talk method as commonly named as the traditional method assuming that there was neither a chemistry laboratory nor any equipment in the school. The second control group of real practical laboratory, the instructor taught the same materials but with demonstration of real equipment. To the experimental group (EG), students were taught based on instructional approach which was enriched by computer animations in the computer laboratory. After the first session of these groups, each group was further divided into two groups to circulate them in the rest groups, forming six (6) groups. Table 1 indicates sequences of various practical delivery modes of chemistry conducted in the study with respective of the number of participants.

For example, students who firstly attended real (hands-on) laboratory were further divided into two groups namely virtual laboratory and paper-based laboratory then further divided into paper-based laboratory and virtual laboratory, respectively. At the end of the instructional session in all six groups, generated knowledge and attitude towards chemistry were tested by considering post- tests to all groups through all stages.

4.3 Data analysis

The results obtained from all tests were analyzed using R 4.1.2 statistical program (https://cran.r-project.org/bin/windows/base/). The descriptive statistics were displayed to describe the characteristics of the students in all groups. The boxplot toolkit for exploratory data analysis was used to compare score patterns distributions across groups. This tool is very useful as it uses robust descriptive summary statistics that always locates at actual data points, are quickly computable and have no turning parameters. The toolkit was applied to determine whether there is a significant difference within groups for results from post-test for each group basing on sequences of experiments' orders for virtual laboratory or paper-based experiences towards hands-on chemistry practical. Such analysis is used to determine to what extent the virtual laboratory or in combination with paper-based practical improves the hands-on practical learning and performance of the students in chemistry for Tanzanian secondary schools.

Table 1 Sequences of various practical delivery modes of chemistry conducted in the study with respective of the number of participants in brackets

Experiment category Experiment orders	1st Category	2nd Category	3rd Category
1st Order	Real (26 students)	Paper-based (13 students)	Virtual (13 students)
		Virtual (13 students)	Paper-based (13 students)
2nd Order	Paper-based (27 students)	Virtual (13 students)	Real (13 students)
		Real (14 students)	Virtual (14 students)
3rd Order	Virtual (26 students)	Real (13 students)	Paper-based (13 students
		Paper-based (13 students)	Real (13 students)

5 Results

To explore general knowledge in ICT and chemistry awareness of the participants, all seventy-nine (79) students were introduced to the pre-tests of those subjects. The results of pre-tests indicate average scores of about 71% and 50% with standard deviation of 12% and 11% for ICT and general chemistry, respectively. Thus, the students had relatively close knowledge in general ICT and chemistry. The results of post-tests for this study are presented in three categories depending on the experiment orders/arrangements with a focus on the control groups (CG) which are paper-based practical and hands-on laboratory against the experimental group (EG) which is virtual laboratory. Thus, the results are described according to the arrangements of experiments when the real experiment was in the first, second or third order against to paper-based practical and virtual laboratory experiments. Such arrangements target to observe learning and performance for stand-alone real (hands-on) practical only as well as the contribution of either virtual or paper-based practical towards to improving real (hands-on) practical. Therefore, the following parts provide details of results regarding the specified categories.

5.1 Real (hands-on) to paper-based practical or virtual laboratory experiments

To determine the stand-alone hands-on practical experiment, the arrangements of experiments started with hands-on practical experiment then followed by paper-based practical demonstration or virtual laboratory experiments (First row with 1st Order in Table 1 and Fig. 3). In these experiments, the scores appear to be symmetrically distributed with half of the students being below and above from 45% in the first group with middle score ranging from 32 to 58% (Fig. 3a). Although, the second group had negative skewed scores, which its median performance of 55% implies that the mean score is less than 55% as there are more scores below the mean score (Fig. 3b). The three-fourths of both groups in the real/hands-on experiments scored less or equal to 58%.

Furthermore, the paper-based practical scores appear to be higher for the group of students who went through virtual laboratory than those who went straight to it. In this comparison, symmetrically distributed scores in paper-based practical experiment from real/hands-on experiment through virtual laboratory has half of students scored 59% with the three-fourths being 72% (Fig. 3b). Poor performance appears in paper-based practical experiment followed immediately after real/hands-on experiment, as the half of the scores were mostly about or less than 42%. Thus, when students are firstly introduced to real/hands-on experiments, their scores were relative similar particularly to the three-fourths of all students (about 58%).

Moreover, the three-fourths of the students in the paper-based practical experiments that followed after real/hands-on experiments have poorer scores (about 42%) than if followed by then virtual laboratory (72%). Similarly, the three-fourths of the students in the virtual laboratory following real/hands-on experiments have relatively poorer scores (about 56%) than if followed by then paper-based practical experiments 59%) as both have negative skewed distributions.

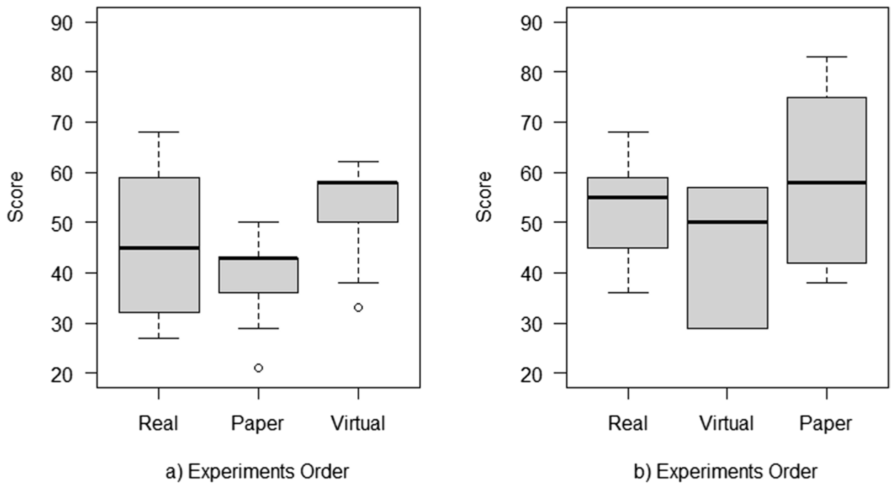

Fig. 3 Boxplot of performance of chemistry hands-on practical experiments in the first order

5.2 Paper-based practical/virtual laboratory to real (hands-on) experiments

To understand individual contribution of both paper-based practical or virtual laboratory to the real/hands-on experiments, two groups were directed to start with those approaches followed by real/hands-on experiments (Second row with 2nd Order in Table 1, and Fig. 4a and b). Figure 4a indicates arrangements of experiments from paper-based practical followed by real/hands-on experiment then virtual laboratory. Figure 4b indicates arrangements of experiments from virtual laboratory followed by real/hands-on experiment then paper-based practical.

The group of students who demonstrated real/hands-on experiment after being exposed to paper-based practical has negative skewed distribution of scores with half of all students being above or below 41% and their three-fourths are with less than or about 48%. Such distribution indicates mean score is less than median score (41%) with majority of scores being below 41%. However, the group of students who demonstrated real/hands-on experiment after being exposed to virtual laboratory has positive skewed distribution of scores with half of them being above or below 41% and the three-fourths of the students with less than or about 57%. Such distribution indicates mean score is greater than median score (41%) with majority of scores being above 41%.

In comparing these two approaches for both experiment arrangements, the highest performance scores appear in paper-based practical experiments after being preceded with virtual laboratory then real/hands-on experiment. In such arrangement, the three-fourths of the students in the paper-based practical experiment score at most 72% with negatively skewed distribution (Fig. 4b). Furthermore, performance in virtual laboratory appears to be improved when it is preceded with paper-based practical through real/hands-on experiment with negatively skewed distribution (Fig. 4a).

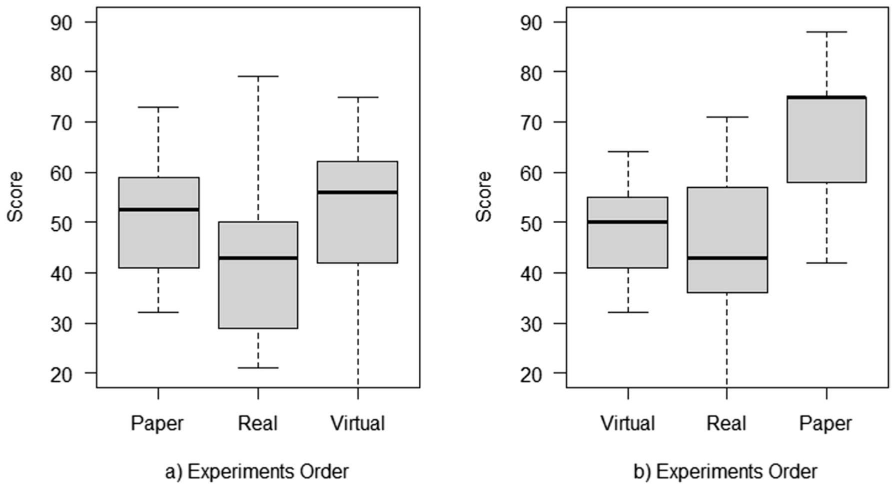

Fig. 4 Boxplot of performance of chemistry hands-on practical experiments in the second order

5.3 Paper-based practical/virtual laboratory to virtual laboratory/paper-based practical to real (hands-on) experiments

To gain better understand on contribution of combined paper-based practical and virtual laboratory to the real/hands-on experiments, two groups were directed to start with those approaches ending with real/hands-on experiments (Third row with 3rd Order in Table 1, and Fig. 5a and b). Figure 5a indicates arrangements of experiments from paper-based practical followed by virtual laboratory then ending with real/hands-on experiment. Figure 5b indicates arrangements of experiments from virtual laboratory followed by paper-based practical then ending with real/hands-on experiment.

Both experiment arrangements indicate the highest scores in the real/hands-on experiments with different in score pattern distribution and progress. In the real/hands-on experiment which is accordingly preceded by paper-based practical and virtual laboratory, the score distribution is positively skewed which implies that mean score is greater than median score which is 65% with higher frequency of high valued scores above 65% (Fig. 5a). In such arrangement of experiment, the three-fourths of the students appear to score about less or equal to 78%. However, in the real/hands-on experiment which is accordingly preceded by virtual laboratory and paper-based practical, the score distribution is relatively symmetric with median score of about 70% as the half of the scores are either above or less than 65% (Fig. 5b). In the latter arrangement of experiment, there is progressively improvement of scores from virtual laboratory to paper-based practical to real/hands-on experiment rather than that from paper-based practical to virtual laboratory then real/hands-on experiment.

Although there are progressively improved perfomance scores for experiment from virtual laboratory to paper-based practical; however, there is strong score drop for experiment arrangement from paper-based practical to virtual laboratory (Fig. 5a).

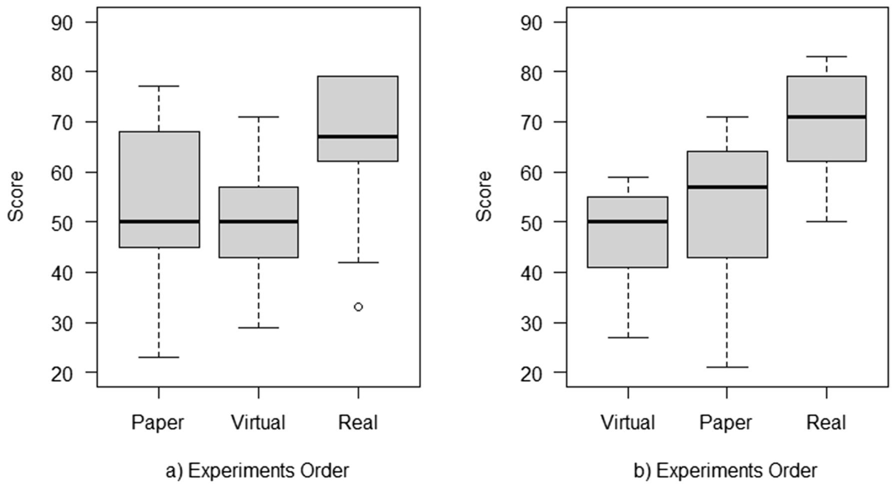

Fig. 5 Boxplot of performance of chemistry hands-on practical experiments in the third order

The group of students who firstly exposed to paper-based practical then virtual laboratory indicates the performance of the three-fourths of the students dropped from positively skewed distribution with 68% to symmetric distribution with 55%, respectively. However, the group of students who firstly exposed to virtual laboratory then paper-based practical indicates progressively improvement of the performance of the three-fourths of the students increased from both negatively skewed distribution with 55% to 64%, respectively. In the latter arrangement, median score (67%) of paper-based practical is higher than that from virtual laboratory (50%).

6 Discussion

Chemistry is among of science subjects, which plays significant role in socio-economic development, as it is a bridging subject for tertiary and university levels for Science, Technology, Engineering and Mathematics (STEM) education and professionals. However, it is difficult for students to construct concepts of this subject as well as those related to STEM subjects or courses. Such difficultness leads to massive failure in these subjects. With focus on Tanzania, the Certificate of Secondary Education Examination (CSEE) in chemistry involves Theory paper, Actual practical paper and Alternative practical paper. The weak performance in chemistry is mainly attributed to poor performance in Actual practical paper and Alternative practical paper. Thus, the problem of science including chemistry is rooted to lack or poor foundation of real/hands-on practical experiments for science subjects. The insufficient or lack of practical experiments are major challenges for chemistry due to insufficient or lack of laboratories, apparatus, expertise or reagents. In addition to scarcity of physical laboratory facilities and personnel, operations of physical laboratories demand physical presence of teachers and students during practical sessions which is time consuming and tricky during pandemic lockdown events like that of Covid-19. Thus, this research uses virtual laboratory approach against paper-based approach to assess improvement of the students' understanding and performance in the Tanzanian secondary school education with a focus in Dodoma region.

A well-designed virtual laboratory for chemistry in Tanzanian secondary schools was deployed at Dodoma Secondary School leading to good results in improving knowledge and altitude of students to the subject. The improvement on learning and performance appears not only to real/hands-on experiments followed by virtual laboratory but also to those followed by paper-based practical. Thus, as revealed by Abdulwahed and Nagy (2009), virtual laboratories are not only used as a substitute to real/hands-on laboratory but they can also be used to supplement the hands-on laboratory and provide effective and rapid learning outcomes in the respective science subject. This virtual laboratory provided clear and enjoyable learning environment as commented by teachers, students and different stakeholders reported by different researchers (Ardac & Akaygun, 2004; Jeschke et al., 2010; Özgür, 2020; Caprara & Caprara, 2022; Leitão et al., 2022). For instance, students who started from virtual laboratory seemed to enjoy in the following stages as they were more aware with all stages than other students. Some students during interview said that, when they came from virtual laboratory to real (hands-on) laboratory, they did not need any guidance or support as they were aware with all steps. Some students liked virtual laboratory as they considered it as computer games.

In fact, chemistry virtual laboratory appeared to be very helpful for students before going to not only actual laboratory but also paper-based practical. Results indicate that students who firstly attended virtual laboratory performed better in real/hands-on laboratory than those who firstly attended real/hands-on laboratory in agreement with (Sypsas & Kalles 2018; Chan et al., 2021; Chinaka, 2021). The best progressive results for real/hands-on experiments appears when the virtual laboratory was followed by paper-based practical ending with real (hands-on) experiments. Thus, such virtual laboratory is a very useful tool for learning practical of chemistry not only to schools without laboratories but also to those with laboratories.

7 Conclusion

Chemistry tends to be the most expensive STEM subject regardless of where one lives. Consequently, majority of chemistry stakeholders are looking for ways to cut the cost and to reduce the use of reagents that might be detrimental to either humans or the environment without losing the needed practical knowledge to progress to the next academic level. Thus, chemistry virtual laboratory appeared to be very helpful for students before going to not only real/hands-on laboratory but also paper-based practical for both schools with and without physical laboratories and facilities. However, development and implementation of virtual laboratory in Tanzania face different challenges including funding, electricity and ICT infrastructure issues as well as poor ICT literacy. Majority of secondary schools in Tanzania do not have ICT infrastructure and electricity. Thus, the implementation of such approach is limited to these schools with electricity and ICT infrastructure.

However, the need of virtual laboratory is higher to majority of schools especially those which do not have not only ICT infrastructure and electricity but also real physical laboratories. The lack of sufficient financial support limits the scale-up of the project to reach to many schools even those with ICT infrastructure and electricity as well as real/hands-on laboratories out of Dodoma region. During testing, some students appeared to be their first time to access computers; thus, the training for virtual laboratory took longer to teach them basics of ICT so that they can carry out their experiments.

Therefore, this study recommends attraction of government and private sectors to support virtual laboratory activities financially and technically in order:

i. To consider solar-powered computers with low costs so as to have alternative electricity;
ii. To scale-up deployment of the developed Chemistry Virtual Laboratory to other secondary schools and if possible, to all public secondary schools in Tanzania as well as development for other science subjects like physics and biology;
iii. To establish Mobile Virtual Laboratory that will be moving from one secondary school to another especially to those schools without ICT infrastructure and electricity as well as real physical laboratory. Such facility will help students to gain more knowledge on the particular science subjects.

It is noteworthy that, digital natives are going to expect schools to prepare them for the technology used today at the university and industrial levels, much of which is becoming more and more virtual and computational sciences. Such virtual and computational sciences can save time and costs for constructions of physical laboratory infrastructures and buying reagents as well as implementation and running of the physical laboratories. Apart from supplementing present scarcity of physical laboratory facilities and personnel, virtual laboratories like this chemistry virtual laboratory remove the demands of physical presence of teachers and students during practical sessions. Therefore, virtual laboratory enables practical experiences even during pandemic lockdown events like that of Covid-19. Thus, the findings of this study add knowledge of virtual laboratory as well as to decision making of policymakers on proper utilization of technology for socio-economic development of the country during normal circumstances as well as during pandemic events like the recent one of Covid-19.

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Declarations

Conflict of interests The author declares that he has no competing interests. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Ethical considerations
This research was conducted only after students and teachers had been informed of the study, and consent was received. Students and teachers were able to decline involvement in the study and informed that they could leave the study at any time. The use of a virtual lab does not create any concerns for student safety or concerns for negative effects on student learning progress. This study values the importance of anonymity and accommodates higher level of privacy and confidentiality on all conversations and data collected. Thus, there was no information that could identify individual students in the study. Gathered data was exclusively used for this study. Respect for the dignity of participants was prioritized and adherence to the existing Data Protection Acts was strictly observed.