Moving Labs out of Labs: Teachers' Perceived Effectiveness of Virtual Laboratories during Pandemic School Closures

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***Abstract*—The extended periods of absence from physical laboratories due to school closures in COVID- 19 pandemic has shortened the contact hours required to develop essential practical skills. This research investigates the perceived effectiveness of upper secondary teachers on virtual labs due to this circumstance. The research participants are subject-matter physics specialists who have been teaching upper secondary students in both learning environments, physical and online. The instruments used in this research are survey, an open-ended questionnaire, and a semi-structured interview protocol. The findings of this research postulated that teaching physics practical skills using virtual laboratories has its limitations, however, the disruption caused by the COVID-19 pandemic has encouraged teachers to explore opportunities that are more effective in teaching physics practical skills. Nevertheless, the effectiveness of teaching physics practical skills using virtual laboratories is confined by the inability to provide students with a similar experience to the traditional labs. Despite its limitations, teaching physics practical skills using virtual laboratories is effective in supporting students through memorizing and comprehending practical skills. The research also revealed that teaching physics practical skills using virtual laboratories is an effective method of encouraging students to apply their existing knowledge and comprehension to unfamiliar situations and draw connections to analyze the physics phenomena.**

***Index Terms*—Practical skills development, traditional and non-traditional laboratories, scientific investigation.**

I. Introduction

Schools in Malaysia were closed in March 2020 when the country first went into a Movement Control Order [1]. Due to nationwide lockdown, teachers and students no longer had access to physical school science laboratories and teaching and learning of practical skills were conducted through virtual laboratories for the first time. The extended periods of absence from physical school science laboratories limited the number of hours students had to develop their practical skills which is an essential component of their high-stakes upper secondary summative assessment. The aim of this study is to investigate the perceived effectiveness of teaching and learning of upper secondary school teachers on physics practical skills using virtual laboratories faced.

II. Statement of the Problem

Practical component is a crucial part of assessment in science because it teaches students to practice the skills to scientific inquiry that help make up science literacy among learners [2]. Hence, all science curriculum, and in this case, Cambridge IGCSE program at an upper secondary level, require 130 contact hours for the teaching and learning of each science subject, which includes practical sessions in science laboratories. Assessment for each science subject comprises three component papers - a multiple choice paper, a theory paper and an option between practical paper and alternative to practical paper. The credibility of developing learner's scientific inquiry skills through performing experiments are well established by many curriculum standards around the world [2]-[4] but whether the same skills can be developed via engaging the students in virtual labs are not certain.

This year (2021), most students were registered for the alternative to practical component paper due to the lack of time spent physically in school science laboratories. Although Cambridge has a provision of an alternative to practical examination component paper, practical skills are required to be taught and learnt according to a Scheme of Work that was drawn up with a physical learning environment in mind, i.e. students are present physically in school science laboratories. Due to the pandemic which led to school closures, a majority of the 130 contact hours were spent by teachers and students being engaged in an online environment where teaching and learning of practical skills took place using virtual laboratories. This study is to determine the effectiveness and challenges faced by upper secondary teachers during the teaching and learning of physics practical skills using virtual laboratories. The effectiveness is investigated from three domains as suggested by the framework developed by Madathil *et al.* [5] and Nemoto & Beglar [6].

- memorization and comprehension of a practical skill using virtual laboratories;
- ability of the student to apply what was learnt and to better analyze the problem;
- engagement levels during the learning of physics practical skills using virtual laboratories.

Considering this, the research questions are as follows.

How effective is the teaching and learning of physics practical skills using virtual laboratories based on the three

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domains: comprehension of practical skills, application of theories into practice and student engagement levels?

III. Literature Review

Scientific investigations require students to formulate a question, perform research using the theoretical knowledge and understanding they have gained, establish a hypothesis, conduct an experiment to test their hypothesis, make observations, analyze their results, and draw a conclusion. The integration of technology in the learning of science equips students with 21st Century Skills such as critical thinking, collaboration and creativity. This can be realized by using the technological, pedagogical and content knowledge (TPACK) concept to build students' scientific attitude and improve their higher order thinking skills (HOTS). Research conducted in the teaching and learning of Physics suggested that the use of virtual laboratories increased student motivation as well as enhancement of scientific attitudes and improved their Higher Order Thinking Skills (HOTS) score [7].

A. Pedagogy during the Pandemic

As schools around the world switched to online learning, the concept of pandemic pedagogy emerged, and educators worldwide came together to navigate online education [8]. The areas examined are the home learning environment, the effectiveness of synchronous and asynchronous learning as well as opportunity frames of online education.

B. Home Learning Environment

The pandemic pedagogy witnessed concerns when home became the learning environment. These concerns include a) lack of basic tools for and contested space for online education, b) sense of being deprived due to confinement at home, c) lack of conducive environment for the exploration and expansion of students identifies and ideals and d) blurred boundaries between workspace and personal space [9]. Due to this shift in the learning environment, students were concerned about lack of interaction with their peers and consequently developing feelings of stress, fear and isolation [10], [11]. The home learning environment offers many teaching and learning opportunities for practical skills, where students are able to conduct simple scientific investigations remotely, ranging from simple concepts such as density to more complex concepts such as electromagnetism. However, these scientific investigations conducted as a remote laboratory setup requires meticulous planning as safety considerations must be prioritized since supervision is limited in the home learning environment.

A. Synchronous and asynchronous learning

With the emergence of online education, many communication and interaction tools were made available to support synchronous and asynchronous learning. However, the selection of these tools depends on the functionality of the tool and how well it aligns to the learning objectives [11]. Synchronous learning is beneficial in that it maintains the structure of a physical lesson emulating the same teacher-student and peer interaction which is lacking in a home learning environment [9]. Furthermore, regular synchronous learning aids in time management, self-discipline, and commitment to learning. The drawback to synchronous learning is it is biased towards students who are privileged, a disadvantage to students with life circumstances which impedes their time commitment. Asynchronous learning would be the preferred option in this regard apart from encouraging reflection and critical thinking to a level that students may not be able to achieve during live discourse [11]. However, reports suggest that teachers were retrofitting their face-to-face teaching and learning approaches into the online learning model in order to best achieve the same outcome [12]. As teachers, teaching and learning in an online environment is not part of the teacher training program and this rendered teachers unprepared while they chartered into unfamiliar territory of online education.

C. Effectiveness of Teaching and Learning Physics Practical Skills Using Virtual Laboratories

The measure of effectiveness from the perspective of the student was analyzed based on three domains [5], [6]:

- memorization and comprehension of a practical skill using virtual laboratories;
- ability of the student to apply what was learnt and to better analyze the problem;
- engagement levels during the learning of physics practical skills using virtual laboratories.

Research suggests that using computer simulations including gamification and virtual laboratories has a generally positive attitude on students and they become better learners. Some research on the other hand defends that there are no significant differences in outcomes of learning using traditional and non-traditional laboratories [13].

The first domain in determining effectiveness of learning physics practical skills using virtual laboratories is the ease with which students memorize and comprehend a practical skill using the virtual laboratories [13]. For instance, students can visualize the change in field line densities which is directly proportional to the strength of a field which otherwise would be invisible, for instance a force field when using computer simulations. Carefully designed virtual laboratories are effective in developing the lower-level cognitive abilities, namely knowledge and comprehension of the Bloom's Taxonomy. Home-based experiments and computer simulations that are fit-for-purpose provides students with the ability to recall facts and basic physics concepts and thereafter explain the idea or the concept in a familiar application. This is supported by research that postulates some computer simulations are capable of eliminating misconceptions which would normally lead to negative attitude, poor cognitive development and low academic achievement [13].

The second domain in ascertaining the effectiveness of learning physics practical skills using virtual laboratories is the ability of the student to apply what was learnt and to better analyze the problem using virtual laboratories. Problem-Based Learning (PBL) using simulation game strategies are an effective method of encouraging students to apply their existing knowledge and comprehension to unfamiliar situations and draw connections to analyze the physics phenomena, rendering them working on the application and analysis cognitive ability levels of the Bloom's Taxonomy. Study reports that virtual physics laboratories were considered most successful when students collected their own data as opposed to using data collected by others (secondhand data) [14]. Students were able to apply their knowledge and understanding not only to familiar applications but extended themselves to solve problems for unfamiliar applications using games strategy to solve problems as they were driven to solve the problem which was seen as the obstacle instead of the fact that the application was unfamiliar. Students had the freedom of choice and engaged in collecting data through video experiments or video demonstrations, or generating data from simulations, or analyzing data trends from preset data without engaging in actual experimental equipment. The integration of technology in the learning of science equips students with 21st Century Skills such as critical thinking, collaboration and creativity [15]. This can be realized by using the technological, pedagogical and content knowledge (TPACK) concept to build students' scientific attitude and improve their higher order thinking skills (HOTS). Research conducted in the teaching and learning of physics suggested that the use of an excel spreadsheet for data calculation and tabulation followed by graphing which emulates a virtual laboratory setup indicated an increase of student motivation as well as enhancement of scientific attitudes and improved HOTS score [14].

The third domain in determining effectiveness of learning physics practical skills using virtual laboratories is the engagement level. Based on literature, from students' perspective, virtual laboratories were deemed better than traditional laboratories as it enabled them to work at their own pace and control their learning. Students also appreciated that a synchronous learning environment supported their peer collaboration and they could have discussions with their peers online asynchronously in the event they required further support or discourse [16]. However, the self-regulatory, motivational and social characteristics of students play an important role in their levels of engagement during online learning [15]. Through the researcher's experience and peer collaboration, student engagement levels can be retained by adopting a blended model consisting of a synchronous and asynchronous learning environment including rotating through small group discussions in order for teachers to effectively utilize teaching and learning contact time.

D. Limitations of Teaching and Learning Physics Practical Skills Using Virtual Laboratories

The literature review suggests pertinent areas that were identified as challenges faced in general by teachers and students during online teaching and learning [6]. Students faced challenges with equipment use / hands-on skills, peer learning, access to teachers and access to technology. Teachers on the other hand faced challenges with providing students with a similar experience to the traditional labs, time and technological constraints, covering the same physics concepts, meeting the course learning objectives, class attendance and participation, budgetary constraints and assessing students.

Based on the literature, the greatest challenge faced by teachers when teaching practical skills was providing students with a similar experience to the traditional laboratory setup [17] and this contributed to the decrease in student motivation. Literature supports that in terms of practical skills, not only do students miss out on performing experiments with physical materials, they also struggle with not being able to have peer discussions and peer support while conducting practicals using virtual laboratories [17]. However, there are a few procedural skills that are difficult to replicate using virtual laboratory setup and this has hindered teachers from being able to effectively teach practical skills using virtual laboratories.

Teaching and learning practical skills using virtual laboratories requires the use of technological tools and these lessons are mostly taught asynchronously during school closure. The need for teachers to acquire Techno-pedagogy Content Knowledge (TPACK) was reported to be more dire during the pandemic, to ensure that the learning outcomes are met with the use of appropriate technological tools [18]. The unsupervised nature of asynchronous learning experience is a barrier for students from engaging in real time questioning with their teachers [19]. Teachers would inherently struggle with formative assessments to ascertain if learning outcomes are met. The success of asynchronous lessons are subject to students' time management, self-discipline and commitment to learning [11]. Studies suggest that a blended model of synchronous and asynchronous learning environment during the teaching and learning of practical skills using virtual laboratories would provide teachers with the opportunities to provide instant feedback and creates opportunities for students to communicate and collaborate while working on scientific investigation [20].

Prior to the pandemic, the use of online teaching and learning tools were already present in some institutions, however this did not encompass a large part of lessons [21]. In institutions where technological tools were not part of daily lessons, the shift to online education saw many challenges including lack of infrastructure and online education policies, lack of awareness around the use of technological tools as well as lack of skills in selecting the appropriate technological tools that align to the learning outcomes [22]. In other situations, technological limitations include infrastructure for accessibility to the internet, power interruptions and accessibility to mobile devices, which would be prevalent in under-developed countries [22].

IV. METHODOLOGY

This research adopts a qualitative design as it is concerned with experience as it is 'lived' or 'felt' or 'undergone'. Themes and domains within the context of this research that aims to investigate the effectiveness and limitations of teaching and learning of physics practical skills using virtual laboratories from the perspective of teachers, were deduced from the literature review.

Qualitative case-study research was chosen to evaluate the effectiveness of teaching and learning physics practical skills using virtual laboratories from the perspective of teachers, as well as to gain deeper insight into the challenges faced by teachers during the teaching and learning of physics practical skills using virtual laboratories.

Triangulation of data was achieved by using more than one instrument to collect data. This supports the principle in research that the phenomena be viewed and explored from multiple perspectives [23]. The three instruments used in this research are Likert-scale and open-ended questionnaires as well as a series of semi-structured interviews.

A. *Selection of Participants*

This research is based on a cross-sectional intrinsic case study [23]. The teachers selected to participate in the questionnaires of this research are from the secondary science department.12 teachers in total that have been teaching practical sciences for more than three years participated in this study. These teachers have had experience teaching students' practical skills in traditional laboratories and have also now taught students practical skills via the virtual laboratories. From the group of twelve teachers, three teachers were chosen for the interviews. These three teachers are subject-matter physics specialist teachers who have been teaching upper secondary Physics in both learning environments, physical and online, where they have completed 70% of the 130 contact hours of learning via online education due to the school closures. All three teachers have obtained their certification by Cambridge through the Cambridge International Certificate in Teaching and Learning (CIATL) and are from the same school. All of them are familiar with both the National Curriculum Physics syllabus and the Cambridge IGCSE Physics syllabus.

B. *Research Instruments*

This research utilized three instruments which are a survey, an open-ended questionnaire and an interview protocol. Both the survey and open-ended questionnaire were adapted from an empirical study that was designed to measure the effectiveness of integrating virtual reality into an online asynchronous learning environment [5]. In order to obtain interview data with sufficient depth and breadth of the experience, a sequence of three interviews were conducted, with a 2-day gap, each interview with a duration of approximately 20 minutes.

A pilot test was conducted on two teachers that were outside of the twelve participants that were selected for the questionnaires. These two teachers predominantly teach physics, chemistry and biology practical skills. This selection was purposefully made to obtain the perspectives of teachers that teach all three strands of sciences and were subject matter experts in either one of the sciences. From the findings of the pilot test, two questions in the questionnaire were amended due to ambiguous language in relation to the concept of communication and collaboration of students as well as the planning of scientific investigations. No changes were made to the interview questions, but suggestions were made on additional prompts and probes. Prior to data collection, in view of ethical consideration, the teachers received an explanation of the research, including the purpose, context and phenomenon that is being investigated. Human Ethics Committees, a committee which governs the ethics of research at the researchers' institution reviewed and approved for this study to be conducted prior to data collection.

V. Findings and Discussions

The analysis of this qualitative case study was based on a framework analysis that comprises several stages including a) data familiarization; b) developing and applying codes (coding); c) identifying themes, patterns, and relationships (charting and mapping); and d) interpreting data.

This study aimed to answer the following question: How effective is the teaching and learning of physics practical skills using virtual laboratories based on the three domains: comprehension of practical skills, application of theories into practice and student engagement levels? The measure of effectiveness from the perspective of the teacher was analyzed based on three domains [5], [6]:

A. *Domain 1: Comprehension of Practical Skills*

The responses from the participants demonstrated that teaching and learning of physics practical skills using virtual laboratories was effective in supporting students' comprehension and memorizing selected physics theories and limited number of practical skills. To understand abstract physics concepts, students require spatial ability to be able to visualize theoretical knowledge and engage in deep learning as opposed to skills required for rote or surface learning, for instance to memorize definitions and physics laws. Turning to an example quoted by one of the participants, the concept of kinetic theory of particles, in one of the teachers' online lessons, he points out that "students were able to view changes in the arrangement and movement of particles in real time (Participant A)" using a simulation tool. Another teacher used the concept of magnetic field lines and factors affecting the strength of magnetic field while another used abstract physics concept as an example when stating that students found it "good to see and visualize on the simulations, especially the magnetic field lines and how the strengths can be increased and decreased (Participant B)".

Using virtual laboratories such as computer simulations, students are able to visualize the change in field line densities which is directly proportional to the strength of a field which otherwise would be invisible, for instance a force field. The researcher believes that carefully designed virtual laboratories are effective in developing the lower level cognitive abilities, namely knowledge and comprehension of the Bloom's Taxonomy. Home based experiments and computer simulations that are fit-for-purpose provides students with the ability to recall facts and basic physics concepts and thereafter explain the idea or the concept in a familiar application. A direct implication of this is seen in the researcher's own classroom when students were able to use a computer simulation to determine the factors that affected the speed of rotation of a D.C. motor, one of which was to increase the number of permanent magnets. As two out of the three participants agree that the simulations provide an opportunity for students to visualize abstract physics phenomena. This is supported by research that also postulates some computer simulations are capable of eliminating misconceptions which would normally lead to negative attitude, poor cognitive development and low academic achievement [13].

Based on the principles of constructivism, knowledge and skill are personal and are constructed in the mind of the learner [23]. Therefore, a learner's prior knowledge and skills greatly influences learning in constructivism. Learners need to actively participate in order to make meaningful connections between their prior knowledge and new learning [3]. The option for asynchronous learning using virtual laboratories also allows a learner to repeat the experiment to support their individual cognitive ability to memorize and make links to comprehend a practical skill. As one teacher agrees, the virtual laboratories provide his students an avenue to repeat the experiment as many times as they require. Using virtual laboratories such as computer simulations, students can understand complex or abstract concepts. The researcher believes that carefully designed virtual laboratories are effective in developing the lower-level cognitive abilities, namely knowledge and comprehension of the Bloom's Taxonomy.

From the aspect of memorizing a physics concept which would be required to successfully conduct a physics practical, virtual laboratories provide opportunities for students to repeatedly attempt or periodically review the home based practical or the simulations as many times as they require to improve their memory retention. As one teacher (Participant C) agrees, the virtual laboratories provide his students an avenue to repeat the experiment as many times as they require. Some simulations provide students with the freedom of presentation, which would mean that the way in which the information is presented can be suited to the students' learning styles. For instance, in one of the teachers (Participant B) lessons where students were required to design a reservoir, students who were visual learners opted for analog pressure gauges where they measured values of pressure using a visual of the pressure gauge while students who were auditory learners opted for digital pressure gauges where they used the speaker button to listen to the pressure readings from the digital gauge. The teacher postulated that "students had the freedom of choice on how their learning was to be presented (Participant B)", he stated when using the simulation tool and the option to toggle from visual and auditory learning provided students the opportunity to experience learning in different styles.

B. Domain 2: Application of Theories into Practice

The theoretical physics concepts that students learn in the classroom are applied during physics experiments, where students are required to apply their knowledge and understanding in both familiar and unfamiliar situations. It is during this time where teachers would normally address misconceptions and students have the opportunity to analyze the data they have collected to validate their hypothesis. To begin the investigation, students would need to decide on the variables involved and two teachers agreed that the virtual laboratories provided an opportunity for students to successfully identify the variables independently by "trial and error". The flexibility provided by the simulations and the gamification of the lab work provided intrinsic motivation. This is evident by one response saying "my students didn't give-up until they obtained the correct variables (Participant B)" and this helped students to identify variables involved to investigate the physics phenomena. Once they had identified the variables, students proceeded to manipulate the independent variable and observe or measure the dependent variable.

Using the simulation tools, students can observe the changes and record their data. One teacher confirms that "Students could change the temperature and watch the vibration of the particles and how they changed (Participant A)" and thereafter record their observations for further analysis. Another teacher explained that her students were able to perform a complex practical activity using a simulation tool and successfully collect data from the virtual laboratory session to be used in calculations. She ecstatically commented during the interview that "I used the simulation so that students not only were able to 'handle' the experiment but they also carried out the calculations linked to the practical (Participant B)". In her opinion, students were able to apply their theoretical physics concepts that they learnt in the classroom more effectively as the calculations they were performing were based on data they had personally collected and were able to relate to it. Aside from using data for calculation, another teacher (Participant C) created a data template using numbers, an IPAD application, so that her students could collaborate on their data collection and then proceeded with graphing to determine the relationship between the variables involved. She justifies her choice of instruction by stating that "I tried this out in my class as it was meant to increase motivation (Participant C)". She was able to observe that her students were motivated while collaborating as they could analyze the trend in real-time and observe changes in the graph characteristics while plotting the graph using numbers. She also recalls one major success of this lesson being the ability to demonstrate to students the impact an anomaly data will have on their line of best fit. Using a traditional laboratory setup where students and teachers would rely on a graph paper and a ruler to determine the line of best fit, the impact of anomaly data would not be easily visible and would require some amount of imagination on the part of the students. With the simulation tools, the application and analysis of data was carried out with more flexibility.

Study reports that virtual physics laboratories were considered most successful when students collected their own data as opposed to using data collected by others (secondhand data). Students engaged in collecting data through video experiments or video demonstrations, or generating data from simulations, or analyzing data trends from preset data without engaging in actual experimental equipment [15]. During an online lesson, one teacher recalls that he had used a Phet simulation to reinforce the concept of changing states of matter and it also helped students to identify variables involved to investigate the physics phenomena. Research conducted in the teaching and learning of physics suggested that the use of an excel spreadsheet for data calculation and tabulation followed by graphing which emulates a virtual laboratory setup indicated an increase of student motivation as well as enhancement of scientific attitudes and improved HOTS score [14]. According to

Piaget's Theory of Cognitive development, disequilibrium marks the beginning of cognitive development where learning sets in until the learner is able to assimilate and accommodate the new information or experience, thus attaining equilibrium. It is apparent that students must have the opportunity to apply what they have learnt through experiments, and the use of virtual laboratories in collecting experimental data firsthand. This allows teachers to monitor and address students' misunderstandings or misconceptions.

C. Domain 3: Student's Engagement

Maintaining engagement during online education was a common challenge for all the participants in this research. Notwithstanding that, they all agreed that the sharing and collaboration of strategies to keep students engaged online are abundant. One of the teachers mentioned that he had adopted humanism in his online lessons to cater to students' esteem needs. He recalled that although online learning feels "less human (Participant A)", the design of his online lessons were "more human (Participant A)" than his regular face to face lessons. One instance he recalls catering to students' esteem needs is by assigning each student with a role to ensure everyone is getting involved in the discussion/project.

Every week, students have three contact hours during physics and these contact hours are split into two parts; a single lesson which is one hour long and a double lesson which is two hours long. During face-to-face lessons, practical sessions are sometimes used during lessons to create a "wow" factor which teachers design into the double lessons to keep students engaged. With online learning, teachers have lost the opportunity to create the "wow" factor with experiments. For instance, begin a lesson with a "can crush" experiment to get students thinking about pressure changes. All participants of this research agreed that the absence of the "wow" factor in face-to-face practical lessons led to lower engagement levels during online learning. To address the lack of engagement during double lessons, teachers used strategies such as breaking up the lesson into parts with live lessons with the use of virtual laboratory tools and asynchronous self-directed work, using break-out rooms to encourage students to work in groups and prioritizing students' well-being over the need to get through a set number of learning objectives. Teachers proactively adopted the nurturing pedagogy while using home practical and simulation tools wherever possible during their lessons to maintain student engagement.

The participants are from an institution that uses cognitive ability data to inform teaching and learning. This cognitive ability data is obtained from a score of four batteries of tests that students sit for as part of their cognitive assessment test. These 4 batteries of tests include thinking about shapes and patterns (Non-Verbal Reasoning), words (Verbal Reasoning), numbers (Quantitative Reasoning) and some questions are answered by mentally generating and transforming visual images (Spatial Ability) [24]. Unlike the other tests, questions in the Spatial Ability Batteries do not require students to have any prior factual or conceptual knowledge of any kind, beyond that required to access the test instructions. These batteries assess students' general cognitive capacity to solve unfamiliar problems that they have not been directly taught, which is a skill students will need to utilize when applying their physics knowledge and understanding. High spatial ability students are able to create mental representations of complex ideas and mentally manipulate those representations, which is a skill that is needed for creative productivity and theory development in the STEM domains [1]. Nevertheless, two participants (Participant A and Participant C) of this research quoted that "despite having high spatial ability, these students missed having lessons in the lab and often expressed their intention to return to face-to-face learning". Another participant mentioned that some of his high spatial ability students struggled to adapt to the changes during online learning. One of his students' explicitly stated that "I miss having science lessons in the labs, practicals are one of the activities that I look forward to when I have science lessons (Participant B)". This participant believed that this was because virtual laboratories did not allow this student to be more responsive during the learning of physics practical skills.

To maintain student engagement and replicate the environment of the traditional laboratories, participants of this research agree that communication and collaboration is key. Throughout the course of using virtual laboratories during the teaching and learning of physics practical skills, the participants have explored various tools and strategies to encourage communication and collaboration as well as access for them as teachers to provide feedback to their students during these virtual laboratory sessions. One participant (Participant B) mentioned that he used Google Slides and Jamboard very often as a tool to encourage collaboration, not just during online learning but also during the current hybrid learning environment. Students would use this platform for the purpose of collaborating while planning the practicals, collecting, and analysing data as a group and finally drawing up their conclusions. While working in groups maintains engagement, the selection of group members is crucial to ensure students are comfortable to communicate and collaborate with one another.

Based on literature, from the student's perspective, virtual laboratories were deemed better than traditional laboratories as it enabled them to work at their own pace and control their learning. Students also appreciated that a synchronous learning environment supported their peer collaboration and they could have discussions with their peers online asynchronously in the event they required further support or discourse [17]. However, the self-regulatory, motivational, and social characteristics of students play an important role in their levels of engagement during online learning [15]. One participant of this research who has a distribution of students with high Spatial Ability test score observes that these students are able to create mental representations of complex ideas and then mentally manipulate those representations, which is a skill that is needed for creative productivity and theory development in the STEM domains [20].

Nevertheless, another teacher notes that one of her students during the initial stages of virtual learning, struggled with adapting to the changes moving from a face-to-face environment to a completely online setting although this student had a high cognitive ability. The teacher observed that this student took responsibility for his learning and communicated these challenges to his parents and teachers. Gradually, he implemented a few strategies that enabled him to efficiently and effectively learn online. Although this was the case, all participants agreed that students were generally looking forward to returning to face-to-face learning when they will be able to conduct physics practicals in the traditional laboratory setup. This suggests that perceived student engagement level is affected not only by their cognitive ability but also by the changes in their study progress levels concerning behavioural aspects.

These findings are in-line with Humanistic theory. Humanists believe that learners are people with individual aspirations. Therefore, teaching and learning according to humanism is determined by emotions. Technology can be used by a teacher adhering to humanism if stress and fear are reduced as this would have negative impacts on learning. Technology can be used to increase self-efficacy, self-assurance, and intrinsic motivation to increase learning. In short, a teacher who adheres to the principles of humanism would use technology to create a learning environment that is inclusive. To achieve self-actualization, a learner needs to know themselves, their behaviors and patterns and technology has been incorporated into humanistic activities in the classroom [9] to support this. Some teachers adopt humanism in their online lessons by building relationships with students during lesson starters and prioritizing their wellbeing over the need to complete a set of learning objectives.

In a virtual setting, engagement levels are maintained through peer collaboration in breakout rooms where students can have discussions with their peers online asynchronously in the event they require further support or discourse [17]. All teachers are seen to utilize break-out rooms to make provisions for students to work in groups. Group assignments are mostly made by teachers and each student is assigned with a role to ensure everyone is getting involved in the discussion/project. Nevertheless, the loss in interaction time with teachers and peers as well as the absence of the "wow" factor in face-to-face practical lessons had led to lower engagement levels during online learning.

VI. Discussion

The findings of this research postulate that teaching physics practical skills using virtual laboratories has its limitations, however, the disruption caused by the COVID-19 pandemic has encouraged teachers to explore opportunities that are more effective in teaching physics practical skills. Nevertheless, the effectiveness of teaching physics practical skills using virtual laboratories is confined by the inability to provide students with a similar experience to the traditional labs while time and technological constraints appear to make teaching physics practical skills using virtual laboratories less efficient. The inability to provide students with a similar experience to the traditional labs limits the scope of teaching procedural hands-on skills and safety skills. However, based on findings, teachers are beginning to recognize that virtual laboratories do enable the teaching and learning of select practical skills relatively quickly and students have an opportunity to conduct these scientific investigations that they would otherwise not be able to conduct in the traditional laboratory environment. Another aspect of replicating the traditional laboratory experience that appears to be a limitation is the inability to create a learning environment where providing and receiving teacher and peers feedback occurs seamlessly. Despite the myriad of technological tools available, the challenge of providing timely feedback is prevalent in the virtual laboratory setting.

This research also revealed that teaching physics practical skills using virtual laboratories is an effective method of encouraging students to apply their existing knowledge and comprehension to unfamiliar situations and draw connections to analyze the physics phenomena. Virtual laboratories tools such as simulations provide an opportunity for problem-based learning using real life applications where students can apply their knowledge and understanding to test their hypotheses while collecting relevant data. With firsthand knowledge of data collection, students were able to make links to their learning and draw meaningful conclusions. The use of virtual laboratories also increases self-efficacy, self-assurance and serves as intrinsic motivation to increase engagement levels during teaching and learning provided the principles of humanism are adhered to in the teaching approach. This includes the ability for students to work in their own time and repeat the scientific investigations when required to improve their memory and comprehension while retaining their confidence.

Considering the afore-mentioned findings, it is apparent that the use of virtual laboratories for the teaching and learning of physics practical skills is effective within the three domains discussed, however, there are limitations which teachers have overcome using various strategies and teaching approaches. With the insights gained from the effectiveness and limitations, the teaching and learning of physics practical skills in traditional laboratories should incorporate the advantages of using virtual laboratory tools.

VII. Conclusion

This research investigated the perceived effectiveness of upper secondary teachers on virtual labs due to this circumstance. The research participants were teachers who have taught in both physical and online learning environments. Through the use of survey, an open-ended questionnaire, and a semi-structured interview protocol, it was found that teaching physics practical skills using virtual laboratories had its limitations, but allowed teachers to explore opportunities that are more effective in teaching physics practical skills. Despite its limitations, teaching physics practical skills using virtual laboratories is effective in supporting students through memorizing and comprehending practical skills. The research also revealed that teaching physics practical skills using virtual laboratories is an effective method of encouraging students to apply their existing knowledge and comprehension to unfamiliar situations and draw connections to analyze the physics phenomena. Due to the limitation that this research was conducted only on one school, future work involving more schools would provide findings that can be generalized.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jasmine Jain suggested the research objectives and proposed the refinement of research validity and reliability. Manmeet Kaur reviewed literature and collected data. Both authors participated in the analyses of data and in the writing of this paper. Both authors had approved the final version.

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