A decade evolution of virtual and remote laboratories

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ABSTRACT

The conventional-experimental laboratory presents problems with time, expenses, risks, distances, and space. Thus, the potential solution to such problems is a virtual and remote laboratory that uses web or mobile applications and internet networks for virtual learning. This paper discusses the recent evolution of virtual and remote laboratories in the last decade. An in-depth literature review is performed to discover any facts about VR laboratory development. The results of this review may lead to the future evolution of remote and virtual laboratories.

1. Introduction

Experiments are essential in school courses and demonstrate a series of scientific procedures to discover a particular goal. School researchers, teachers, or students perform their experiments in a laboratory (lab). Teachers use the lab for teaching as well as storing their scientific equipment. However, some schools have problems with setting up a laboratory. The laboratory requires an extensive and safe area, along with a great maintenance budget and also inflexible operational time. Thus, technological solutions are needed to encounter these crucial problems.

One available solution for those problems is using virtual and remote laboratories. A virtual laboratory virtualizes a real lab using 3D images and interactive videos. Students may freely perform the research simulation without being afraid of damaging any equipment in the lab. On the other hand, a remote laboratory permits students to conduct experiments and other laboratory tasks through the Internet even though they are not in the same location as the real apparatus. Additionally, they can perform an actual experiment without concern about time and place constraints. Lastly, this solution may transform monotonous learning into more fun and enjoyable learning.

This paper examines the most recent expansion of virtual and remote laboratories. We conduct a review of 36 online articles pertaining to virtual and remote laboratories. The review is divided into four sections. The first and second sections discuss the recent evolution of virtual and remote laboratories separately. Meanwhile, the third discusses the dangers associated with implementing both technologies as well as their future development.

2. Method

2.1. Virtual laboratory in a decade

The virtual laboratory (Fig. 1) represents the use of computer technology to efficiently and interactively simulate experiments in a laboratory. The first version of this technology was reported

in 1977 in the form of a virtual laboratory for psychology. It continues growing over time, along with the development of other technology and human needs.

In 2010, a virtual laboratory was implemented in chemical education with collaborative scripts to promote conceptual knowledge. That laboratory facilitates students to attract and release substances and tools for specific problems, as well as completing actions such as mixing and weighing. The virtual laboratory also includes meters and feedback indicators about the characteristics of substances [1].
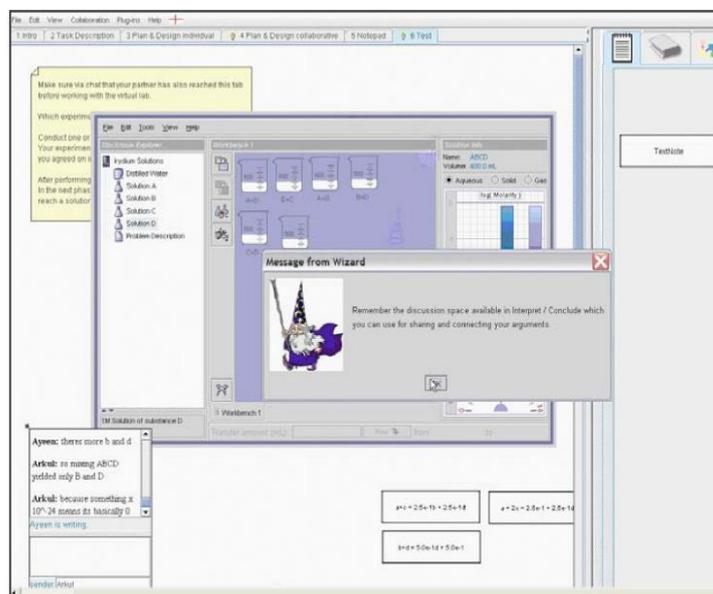
Fig. 1. A screenshot of the computerized CoChemEx script displaying the Test menu

In addition, in 2010, virtual laboratories presented essential roles in engineering education. During this year, a new virtual laboratory method was developed for PLC (Programmable Logic Controller). This virtual laboratory is used to design and implement parts of the mechatronic design with various multiprog languages. Meanwhile, the students are required to monitor processes in this instance, understand the concept of PLC automation and understand virtual laboratory processes (Fig. 2) [2].

In the same year, a virtual epidemic was used to enhance knowledge of infectious diseases, their social implications, and the investigation process. In this virtual epidemic, users can use their own experiences and community observations to learn the process of infection and immunity, social behavior interactions, as well as reactions to perceived health risks. The real-world investigations are difficult to replicate due to ethical considerations. Besides, different learning laboratories can engage students in testing various epidemic simulation parameters, identifying and developing vaccines, analyzing archived records of past epidemics, and discussing ethical issues [3].
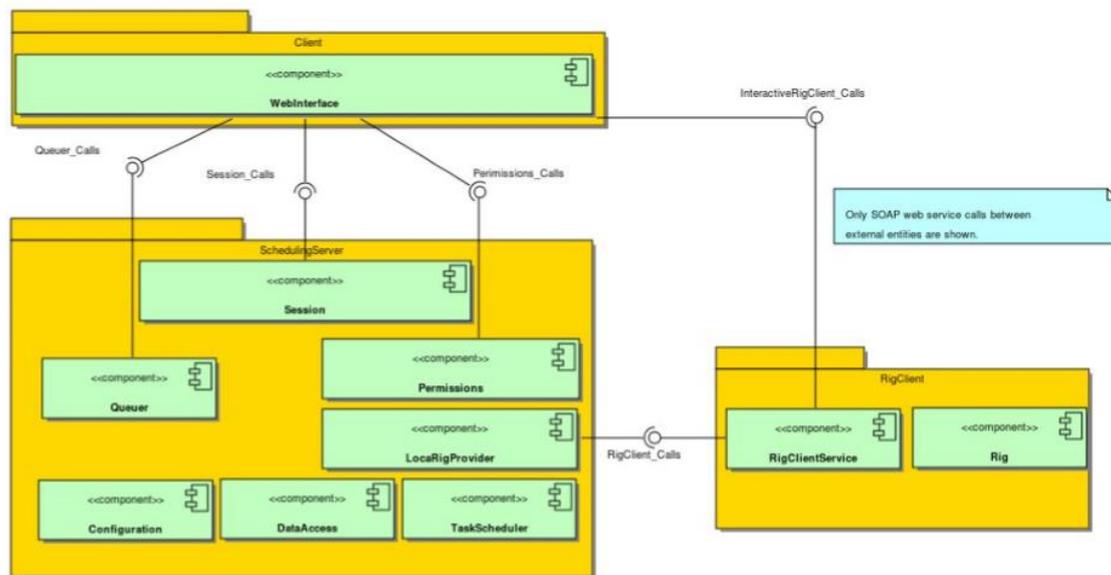
Fig. 2. Component Diagram depicting interfaces of Sahara Release 2. Consists of Scheduling Server, Web Interface Client, and RigClient.

In 2011, the Tele-Lab project was built to address the lack of knowledge about cybersecurity. Tele-lab is a virtual web-based laboratory that can be accessed via http://www.tele-lab.org/. The rising usage of the Internet this year also captivates the attention related to cybersecurity. A previous study reported that some teaching techniques are not suitable for security training because of the inadequate environment [4].

In the same year, virtual laboratories were built to facilitate science education. Virtual laboratories were constructed due to the lack of laboratory equipment, limited time to conduct experiments, high material costs, and attempt to minimize the possible risks from scientific experiments [5].

In 2012, virtual and remote laboratories were developed to overcome problems related to the high cost of equipment in experimental laboratories. For the undergraduate teaching laboratories in the field of optics and microwaves (Fig. 3), the University of Limoges has established a virtual electromagnetic and optical laboratory (LAB-EN-VI) [6].
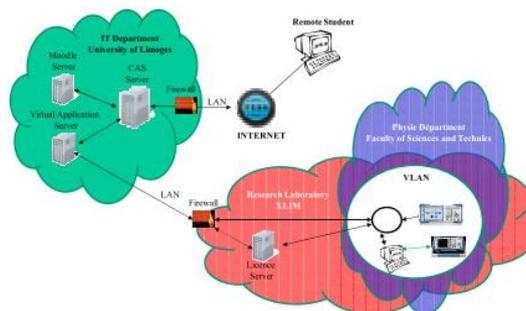
Fig. 3. Architecture of the remote virtual Lab for microwaves

In the same year, an interoperability platform was developed to incorporate virtual and remote access laboratories, increase the versatility of educational resources and adapt to new learning methodologies [7].

Also, in 2012 remote and virtual laboratories were web-based platforms that allowed users to conduct a series of remote and virtual experiments in various fields, such as in education or training in real laboratories using shared data networks [8].

In 2013, for a course with more than one hundred students, a web panel and LabVIEW interface were used to solve problems in virtual experimental settings and the use of remote laboratories. Meanwhile, university policy allocates a disproportionate amount of funds to instructional laboratories [9].

In 2014, a virtual laboratory can also be applied in other fields, such as vlab.co.in a website that can be adopted in the biotechnology field (Fig. 4), which is equipped with animation. The implementation of a virtual laboratory in the field of biotechnology has also been reported in a previous study [10].

In 2015, a project-based virtual laboratory (PBLVL) was developed to increase the knowledge of students, researchers, and members of society working together in various fields and disciplines, especially in heat transfer material. The project is expected to increase students' understanding of entry-level techniques from multiple aspects of heat transfer engineering topics [11].

Also, in 2015 a study investigated a virtual laboratory by giving students remote access to various laboratories in the domain of technical education. Further, the application of cloud computing models in building a virtual laboratory aims to overcome various problems observed in physical laboratories [12].
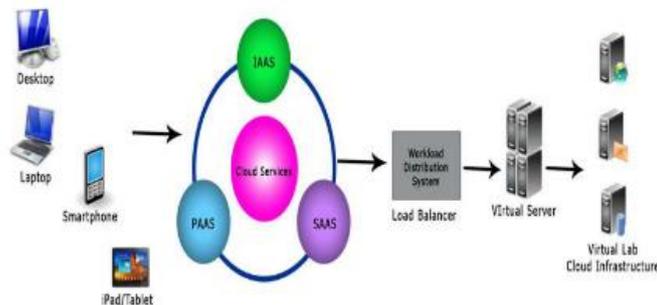
Fig. 4. Logical Diagram of Virtual Labs

In 2016, virtual and remote laboratories became a platform for enhancing user engagement in blended learning scenarios to accelerate university education in India's rural areas [13].

Also, in 2016 a virtual Lab developed with netlab was used to determine the equivalent transformer circuit with LTSpice software [14].

In the same year, a simulation was conducted to reduce the annually increasing greenhouse gases by implementing virtual and remote laboratories. This simulation confirmed that cost transfer techniques help increase the percentage of renewable energy utilization [15].

In 2017, the virtual lab was developed in the nuclear physics field and applied using the monte-Carlo (MEMCM) method (Fig. 5) [16].
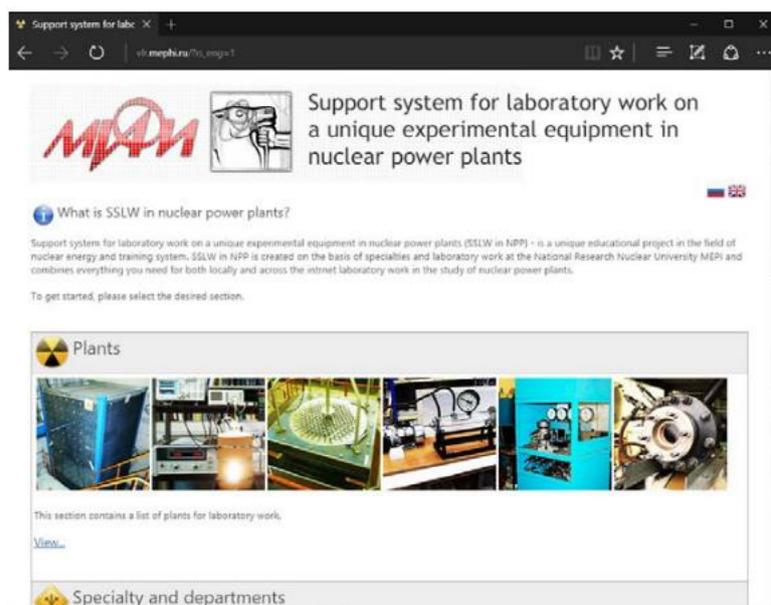
Fig. 5. Homepage of the nuclear power plant laboratory support system for distinctive experimental apparatus

Additionally, in 2017 a web-based virtual and remote laboratory was developed as a learning media for line follower robots learning. It was created using Learning Management System (LMS) with Moodle support connected to the Internet. In addition to using the Learning Management System (LMS), virtual and remote laboratories can also be implemented using netlab in the lecturing process (for lecturers) and completing assignments (for students). Netlab is used for experiments with electronic instruments and actual electrical circuits [17].

In 2018, a virtual lab was implemented with Physics Education Technology (PhET) in the learning of waves and sounds, while the lab can be accessed on the phet.colorado.edu website page [18].

In the same year, a mobile-based virtual laboratory for experimentation was also developed (VL-APP) using Unity3D and 3ds-max software, along with Android for its installation [19].

In 2019, (Fig. 6) multimedia learning in virtual laboratories was supported by pedagogical agents that not only assist but also foster more effective multimedia learning due to motivational factors and its ability to direct student attention toward a more goal-oriented learning process. Additionally, the pedagogical agent also enhances communication between students in the subsequent iteration by, for example, distributing questions, answers, or assistance in study groups [20].

Fig. 6. Left: The orange frame emphasizes the task containing the input field. The student is asked to evaluate her or his self-confidence using the provided response. Right: Presentation of the pedagogical agent and control bar for navigation (left/right arrow), information (i-symbol), tip (Tipp), and cross-symbol to remove the pedagogical agent.

2.2. Ten years of remote laboratory evolution

Remote laboratories (Fig. 7) are a computer-based learning environment that enables students from all over the globe to conduct remote experiments using actual laboratory equipment via the Internet. Different from virtual laboratories, remote laboratories facilitate real experiments in the form of distance learning. This technology has rapidly grown following the progression of the world's digitalization era.

In 2010, different focuses, philosophies, approvals, and domains were reported in vastly distinct technical solutions for remote laboratory support. Aside from demonstrating significant strength in resolving a variety of problems and applications, this diversity does support the division of laboratories among various institutions. Investment in interoperability between two remote laboratory platforms has met the requirement for a common application protocol, so the remote lab can provide the desired services [21].

In the same year, a remote laboratory for electronic teaching was developed named RemoteElecLab. RemoteElecLab combines Learning Management System (LMS) and Moodle (e-learning platform) to facilitate students' interaction daily, aiding them to complete their practical work at home [22].

In 2011, a non-holonomic cellular robot experiment was conducted with a mobile robot to establish a leader-follower using image processing implemented with MatLab and easy Java simulation [23].

Fig. 7. Architecture of the remote lab.

Further, in 2011, remote laboratories also brought an important role in engineering education. Labshare, developed by Australia, is one of the examples of a remote laboratory project. Labshare can be accessed at http://www.labshare.edu.au. Another remote laboratory, named Remote Laboratory, is equipped with a glossary and toolkit that help the faculty member to understand the terminology of remote laboratories [24].

In 2012, Remote laboratories were applied for data acquisition using LabVIEW and NI hardware, one of the integrated development environments widely used for digital signal processing and instrumentation development [25].

In 2013, a virtual and remote laboratory was developed by applying the e-learning methodology in the field of robotics education using EJS, Matlab, and LabVIEW (Fig. 8)[26].
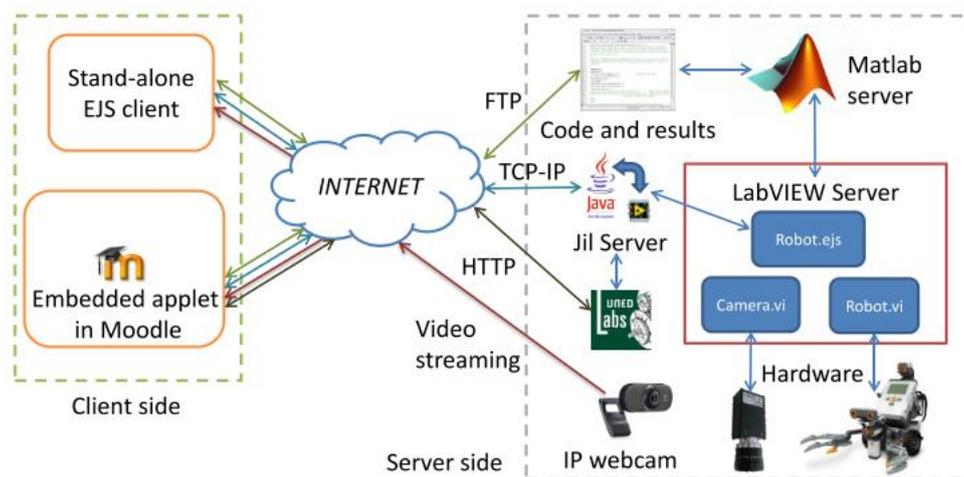
Fig. 8. Laboratory Architecture

Within the same year, a control technique learning laboratory (Fig. 9) was developed using a distributed remote laboratory with a deltaV server and Teamviewer as a remote control. Teamviewer was used to operate an installation integrated with DeltaV from a remote system [27].

In 2014, LabVIEW was used to create a remote laboratory for teaching motion control experiments and control system experiments to engineer mechatronics students with various feedback devices [28].
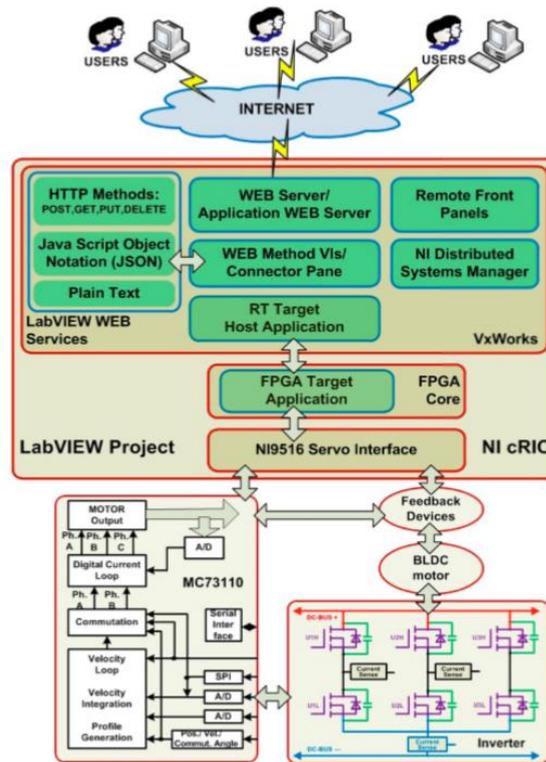
Fig. 9. Architecture of the Remote Motion Control Laboratory

In 2014, the remote laboratory was adopted to overcome existing problems using virtual instrumentation in academic institutions. Besides, it also improved the lectures in the classroom, specifically in completing the learning process, sharing research equipment, and supporting student independent learning activities [29].

In 2015, in a computer-based learning environment, the Remote Laboratory (RL) was developed. It enabled students to remotely access and conduct experiments using actual laboratory apparatus via the Internet from any location. Besides, Facial Expression Recognition (FER) was used to create intelligent systems guiding students and aiding them in enhancing instruction and learning (Fig. 10). This FER may include monitoring tools to generate automatic learning assistance after analyzing their faces and other human features for detecting and measuring frustration, interest, and boredom. In the end, FER assists instructors in their teaching roles, as well as students in overcoming their difficulties during their practical work [30].
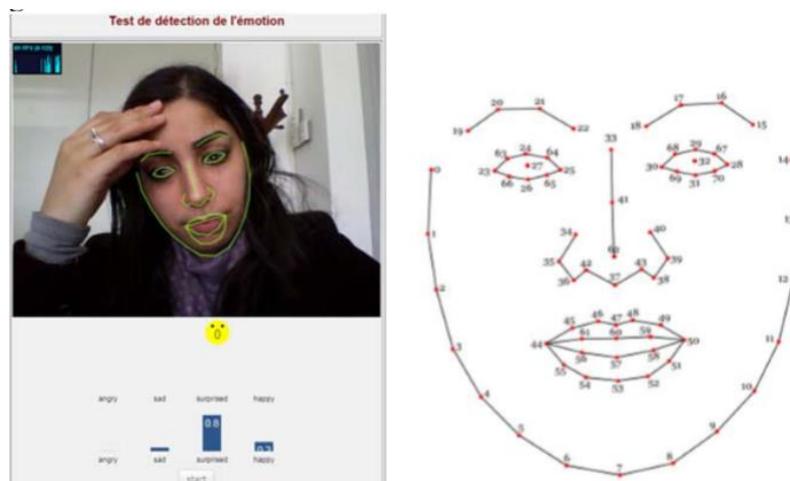
Fig. 10. Learner expression detection interface on the left. Face model recognition JavaScript on the right.

In 2016, a new field of research emerged, namely Learning Analytics (LA). It is an amalgamation of education and computational research methodology in the field of technical education [31].

In the same year, in South India, comparative analyzes of remote learning components were controlled remotely in real time through virtual biotechnology laboratory workshops to improve teaching and learning strategies in the region [32].
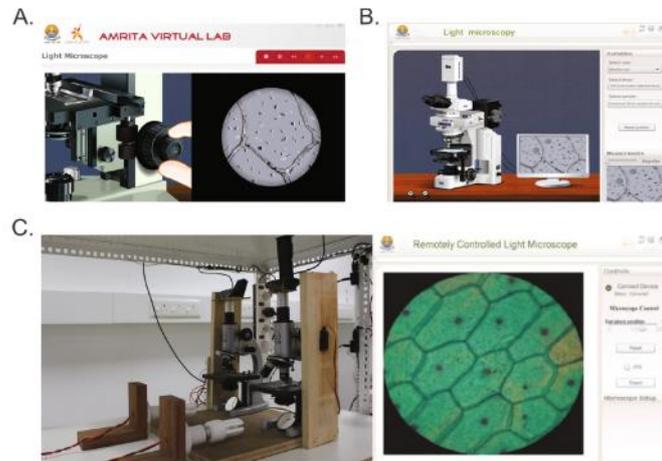
Fig. 11. A. Animation of Light microscope experiment, B. Simulation of Light microscope experiment, C. Remotely controlled Light microscope experiment (freely available via http:// vlab.amrita.edu/).

In 2017, Netlab was used for experiments with electronic instruments and actual electrical circuits (Fig. 12) [33].
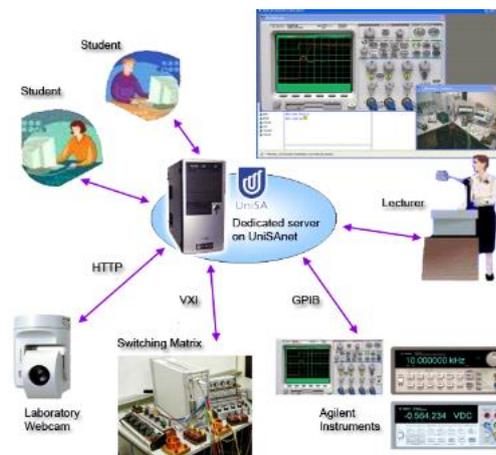
Fig. 12. Structure of NetLab.

In 2018, a website (using HTML or javascript provided by the NodeJs server hosted on Raspberry) was developed for practical electronic work based on embedded systems (Raspberry and Arduino) with intelligent education systems (Fig. 13) [34].
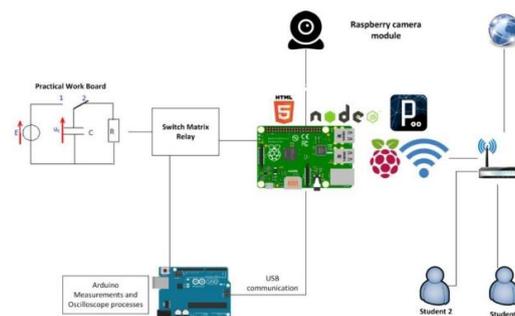
Fig. 13. General architecture.

Also, in 2018 E-Learning Education for Mechatronics Remote Laboratory (EDUMEC) provided courses to introduce diverse good practices related to national and international qualifications of mechatronics vocational training [35].

In 2019, remote laboratories were proposed in two types of architecture. First, a remote laboratory architecture based on Arduino and a reliable PC server for data storage, speed, and processing capacity was developed to test the optimization of irrigation using a solar pump. Meanwhile, the second remote laboratory architecture was used to control the digital electronic experience based on the use of an embedded system - PcDuino used an operating system [36].

3. Results and Discussion

During the evolution of virtual and remote laboratories, various positive and negative impacts have emerged.

A number of its positive impact happens as a consequence of the evolution of virtual and remote laboratories. First, students can understand an experiment because of the unlimited replication of experiments. Second, students can still experiment remotely. Besides, experimenting with virtual and remote laboratories is more economical because they do not need lab tools and materials. Also, the effectiveness of learning increases because students can linger in the lab and do repeated experiments. It also provides higher security and safety because students do not interact directly with authentic tools and chemicals.

Meanwhile, the negative impacts include the absence of real authentic field experience and the lack of actual experience. Therefore, students may confuse about assembling tools and operating them in a real library setting.

In the end, we concluded that the forthcoming of this technology is promising. The subsequent development can be carried out in the dentistry field, which is still experiencing difficulties, especially in dental practices. We propose the idea of a virtual laboratory to design a virtual dental design to help students save time and money because they do not need to carry the activity manually. They can design through the virtual laboratory, then print and use it immediately.

4. Conclusion

To conclude, the development of remote and virtual laboratories is occurring in numerous fields. The virtual laboratory represents the use of computer technology to efficiently and interactively simulate experiments in a lab. Meanwhile, remote laboratories are a computer-based learning environment accessible for students from all over the world. The progression of the virtual laboratory is mainly observed in the field of education. The development of these laboratories was also identified in the engineering and technology fields. Many virtual laboratories are developed based on websites, so they are accessible through the Internet, enabling their usage from anywhere and anytime. Meanwhile, the development of remote laboratories mostly also centralizes the field of education. Most of the remote laboratory development is based on websites and applications. Virtual and remote laboratories have positive effects, specifically in facilitating users to complete a project. However, we also observed some negative effects from the creation of remote and virtual laboratories, such as there being no experience in using physical laboratories. Thus, future remote and virtual laboratories can be developed in various other fields.

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