LEARNING THROUGH VIRTUAL REALITY LABORATORY APPLICATION:
A USER STUDY

By

GHAZALA RASHEED

NATIONAL UNIVERSITY OF MODERN LANGUAGES

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GHAZALA RASHEED

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Submitted by: Ghazala Rasheed   **Registration #:** 008 MSSE/Ibd/F18

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Name of Discipline

Dr. Muzafar Khan   _____
Name of Research Supervisor   Signature of Research Supervisor

Dr. Basit Shahzad   _____
Name of Dean (FE&CS)   Signature of Dean (FE&CS)

Prof. Dr. Muhammad Safeer Awan   _____
Name of Pro-Rector Academics   Signature of Pro-Rector Academics

January 20th, 2022

Date

AUTHOR'S DECLARATION

I <u>Ghazala Rasheed</u>

Daughter of <u>Abdul Rasheed Khan</u>

Registration # <u>008 MSSE/Ibd/F18</u>

Discipline <u>Software Engineering</u>

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<u>Ghazala Rasheed</u>

Name of Candidate

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Date

ABSTRACT

Learning Through Virtual Reality Laboratory Application: A User Study

In today's digital world, smart and emerging technologies like virtual reality are now becoming a necessity in the field of education. The need is instigated by a lack of student's interest and engagement in STEM (Science, technology, engineering, and mathematics) subjects. As a result, student's performance is negatively affected in such subjects. Numerous studies have been conducted to evaluate virtual reality in education but have lacked participants and education level. The purpose of this study is to measure the effectiveness of a virtual laboratory on secondary school students' practical learning of Physics. In this case, a desktop-based virtual laboratory application was developed with four Physics laboratory experiments based on students learning parameters and virtual reality design guidelines which obtained from the literature. The main research methodology was a user study, conducted with 184 participants from 4 secondary schools. Each school consisted of experimental group (used virtual laboratory) and control group (used physical laboratory). The data was collected using a Physics quiz at the end of study from both groups. The results showed, mean score of an experimental group 7.16 was greater than control group mean 5.87. This revealed that participant's learning using virtual laboratory was better than participants of physical laboratory. The results also revealed no significant difference in performance of boys and girls in the two groups. The usability test was completed through SUS (System Usability Scale) questionnaire which included 92 participants of experimental group in order to assess the interface of an application. The internal consistency was measured using Cronbach alpha with an achieved value of 0.76 for the questionnaire. The SUS score was calculated and found results above average with a value of 73.5. The participants who used the virtual laboratory application found it easy to use, user-friendly and helpful for learning.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AR	-	Augmented Reality
CG	-	Control Group
DOF	-	Degree of Freedom
EG	-	Experimental Group
HMD	-	Head Mounted Device
STEM	-	Science, Technology, Engineering and Mathematics
SUS	-	System Usability Scale
UI	-	User Interface
UX	-	User Experience
VR	-	Virtual Reality
VR-Lab	-	Virtual Reality Laboratory

LIST OF SYMBOLS

α	-	Alpha Value
μ	-	Mean
σ	-	Standard Deviation
σ^2	-	Variance

LIST OF APPENDICES

ACKNOWLEDGEMENT

DEDICATION

This thesis work is dedicated to my beloved parents and to the respected teachers who have supported and encouraged me throughout my degree.

CHAPTER 1

INTRODUCTION

1.1   Introduction

A recent development in information technology which attracts researchers is Virtual Reality (VR). VR technology immerses the user into a virtual environment and replaces a real world with a virtual world around the user [1]. Users can experience VR by wearing a head mounted display to see the virtual world. VR is becoming important technology for the business these days for meetings and teleconference [2]. It makes shopping easier for the users, as they feel like they are in the middle of a store but actually they are not, when using such applications [3]. In the field of medicine, VR is also effective in surgery and creating a model of a human body [4]. In the field of entertainment, it is used in games, virtual cinemas and virtual pilot training [5]. The most important field where VR works is in the field of education such as virtual teaching, virtual laboratory, virtual museum, virtual campus etc. [6][7][8].

Among other education technologies, VR has also reshaped the style of learning and teaching such as virtual teaching. It overcomes the traditional teaching method in which students get bored [9] and it is difficult for them to memorize too much information in a short period of time [10]. VR increases the student's interest in learning and engagement. This technology also makes students active learners because VR technology encourages students in decision making, understanding complex problems, learning by doing things and collaborating with other students [11]. Virtual laboratories are also used where there is insufficient infrastructure to develop fully equipped laboratories or the instruments are not enough or expensive. This also helps students to understand how experiments are performed in STEM (Science, technology, engineering, and mathematics) subjects like Biology, Chemistry and Physics.

Many organizations have developed different VR applications in the field of education which are easy to use, affordable and help teachers in their classroom environment. The study [6], introduced a museum tour using VR technology which benefits the learning of museums virtually. VR also plays an important role in teaching students with autism [12]. The usability of a VR is found beneficial in the teaching-learning process of autism students. The researcher [13] developed the affordable and low-cost virtual library application that allows users to experience the immersive technology and view virtual library books. It is also possible in VR to tour historical places for the learning of cultural heritage. The study [14], investigated indoor learning efficiency among middle school children by using a VR application for a tour of historical sites.

Over the past few years, VR technology has shown potential to improve learning methods in comparison to traditional methods. As a result, the educational systems of various countries have adopted VR technology in their education. The new advancements in VR technology are making VR devices appropriate and affordable to different levels of education including primary & secondary schools, colleges and universities. Students in secondary schools need a variety of new skills and knowledge to achieve their goals. They also want to engage with people beyond the walls of a classroom. With their enthusiasm for learning, VR technology increases their learning experience and it can help in visualizing things which they are already learning theoretically.

In education, science laboratories play an important role in increasing the learning abilities of students. These laboratories are built on a physical space and are equipped with instruments or apparatuses in order to perform different kinds of experiments by students. Sometimes the educational institutes fail to provide such facilities to students because of limitations in infrastructure, resources, funding, expensive maintenance and other related issues [15]. The Virtual Reality Laboratory (VR-Lab) plays a vital part in the learning outcome of students in such circumstances [16]. VR-Lab uses the technology of VR for presenting and visualizing the data. VR-Lab is not only a facility for education, but it is an inventive laboratory in which students can explore and learn through virtual environments.

1.2   Problem Statement

Some students of secondary schools show less interest in the STEM subjects like Physics, Chemistry, Mathematics and Biology [17]. Sometimes they face difficulty in learning and performing different science experiments in physical laboratories [18][19]. There is a need to identify the key learning parameters which exist in literature [7]. In order to support VR based learning, there is also a need to identify design guidelines specifically for VR applications from existing studies [20][21]. This determines whether these design guidelines can also be applied in the field of education. Lastly, to identify how students' learning is affected when using the VR application [22].

1.3   Research Questions

i.   What are the key learning parameters for secondary school students?
ii.   What are the design guidelines that exist for VR applications in literature?
iii.   How does the VR-Lab application affect the student's learning?

1.4   Research Methodology

Research methodology is adopted in research process to collect, ensemble and then investigate the data. It is a process to find the answers to research questions by applying different techniques [23]. The study is an exploratory, destined to find key learning parameters and design guidelines for VR. This research demonstrates how these can improve the learning ability of secondary school students. This research uses the quantitative approach which is generalized across a population (survey, experimental and correlational research) [24].

The literature review is a first phase of this research. Any research, independent of discipline, needs previous research to evaluate and justify research questions about the aim of a study. It is the best way to present research findings and reveals areas that need more research

[25]. Thus, this study needs to find the different learning parameters and design guidelines of VR from the existing literature in order to justify this research.

In the second phase, a virtual laboratory application needs to be developed that follows the identified learning parameters and design guidelines from the literature. The need for application development is essential for implementing the identified different learning parameters and design guidelines in virtual technology. This application covers four Physics laboratory experiments which developed in Unity 3D.

The third phase is conducted through a user study. User study by definition is the study of behavior, context and people [26]. In this research, the user study involved students from secondary schools making up two groups in each school. The first group performed experiments using a virtual laboratory and the second group used a physical laboratory. The study investigates learning outcomes through a quiz between two groups. A usability questionnaire is also circulated among students of the experimental group. Usability evaluates the satisfaction and ease of use of an application [27]. This questionnaire tests the findings on what level of learning can be improved through virtual laboratory technology.

1.5   Aim of the Research

The aim of this research is to develop a virtual laboratory application and to evaluate its effectiveness on student's learning.

1.6   Scope of Research Work

The scope of this study is limited to the STEM subjects of Physics for secondary school students, including four experiments developed in a virtual laboratory application.

1.7   Thesis Organization

The rest of a thesis based on 5 chapters which are summarized as:

Chapter 2 provides explanation on traditional laboratory methods and introducing virtual laboratory learning methods. The literature also reviewed and analyzed existing studies.

Chapter 3 investigates the effectiveness of learning through developed virtual laboratory application. It also explains the methodology for a user study to collect and analyze data.

Chapter 4 evaluates the effect of student learning through physical and virtual laboratories. Results inferred by applying different statistical techniques. This chapter also discusses the findings from the study.

Chapter 5 concludes the research and provides suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1   Overview

This chapter provides the theoretical foundation from different research papers & journals. It focuses on discussing the traditional teaching method (section 2.2), introducing Virtual Reality (section 2.3), explaining the role of Virtual Reality in education (section 2.4) and learning in Virtual Reality Laboratory (section 2.5). The section 2.5 also covers the existing studies related to the topic and critically analyzes the existing research. The research also found some key learning parameters (section 2.6) and design guidelines (section 2.7) from literature. The section 2.8 summarized the whole chapter.

2.2   Traditional Teaching Methods

The student's learning is important to activate their undiscovered skills so that they can use the best of them. Also, education increases the decision-making ability of students. The learning of various subjects does not produce the similar outcomes as there are many factors that impact the achievements of the students but the teaching methods nearly have the same impact on student's learning [28]. The main reason of the teaching is to let out the noteworthy change in the students at any level of studies [29].

Most of the traditional methods are teacher-centered, making the students passive with no activity. Therefore, the engagement level of the students is very low towards their subjects. This approach is less practical and more theoretical; making the students memorize a lot of information during the given time span [30]. Whereas the student-centered methods are more

effective and encouraged because the students are trying to adopt the concept of revelation learning [31]. This is why most of the teachers are now applying a student-centered approach in order to improve the interest of students towards their subject and promote the analytical research and critical thinking [32].

In secondary school education, the curricula of STEM (Science, technology, engineering, and mathematics) subjects (like Physics, Biology, Chemistry and Mathematics) inculcate creative thinking, problem solving, self-directed learning of students and enhance the environmental and scientific literacy among the students [33]. But teaching STEM subjects is also creating a dilemma for students as well as for teachers. A lack of interest is seen in all STEM subjects because it is perceived that these subjects are boring and difficult to understand [34] and thus, the students cannot participate actively in the classroom and sometimes fail to achieve high level grades in such subjects. This issue can be resolved by effective instructions from teachers that actively engage the students in Science and Mathematics practices throughout their schooling [35].

Some of the STEM subjects require their own laboratories to perform different experiments. These laboratories help in developing the student's interest in the subject, giving them opportunities to gain practical knowledge and promote understanding of the theories taught [36]. Furthermore, laboratory practices also focus on transferable skills like communication between team members, the management of time and promoting teamwork [37]. The laboratory often tries to put ideas or thoughts into practice and develop the practical skills of the student [38].

In secondary schools, the traditional laboratories exist in a physical location, usually within the school where instructors demonstrate experiments physically and students perform accordingly. Along with the effectiveness of using traditional laboratories, there are also some drawbacks when learning in such laboratories.

1. There are a limited number of experiments that can be performed with limited resources and available time [39].
2. Most of the experiments are dangerous and may lead to accidents if handled incorrectly. In this case, safety cannot be compromised [40].

3. Some secondary schools are struggling with the economic burden of maintaining expensive apparatuses in traditional laboratories [41].

4. The experiments in traditional laboratories are seen as costly because such laboratories require space, infrastructure and demonstrator time etc. These factors may lead to high overall operational costs [42].

5. Due to the lack of resources and space issues, traditional experiments are unable to meet the requirements of the handicapped and distant students [43].

STEM is a discipline that covers Science, Technology, Engineering and Mathematics fields. It offers an approach that encourages students in problem solving, critical thinking and logical thinking about complex scenarios. However, there is still room for improvement in making STEM education more effective. Teachers can support students by upgrading their teaching methods with new strategies such as with the help of technology resources. The technology is considered as an effective substitute to traditional teaching methods because it opens up unlimited opportunities for the students [44].

2.3   Virtual Reality

Virtual Reality (VR) is a human-machine interface that integrates artificial intelligence, computer graphics, networking and image processing in order to create computer simulations. This simulation allows interaction with real time and gives the sensation of being present in a virtual environment through different sensory channels [45]. By definition, VR is an environment created by a computer system that replicates reality. One can immerse themselves in these realities through touch and sight by wearing headsets & special gloves and through hearing by using headphones [46].

Other definitions for VR are also found in the literature such as: according to [47], "the computer technology develops a 3D interactive world in which the user can view and operate with it". Similarly, [48] defined VR as "a computer created environment which allows individuals to practice with different visual and auditory objects and this can be experienced by wearing eye and ear devices". In the figure below (Figure 2.1) a VR system is shown which consists of HMD (Head Mounted Device), 3D mouse and a tracker. When the user is rotating

their head, this behavior is tracked and the data is sent as an input to the computer. The computer processes the data and generates a suitable output which is then sent back to the user.
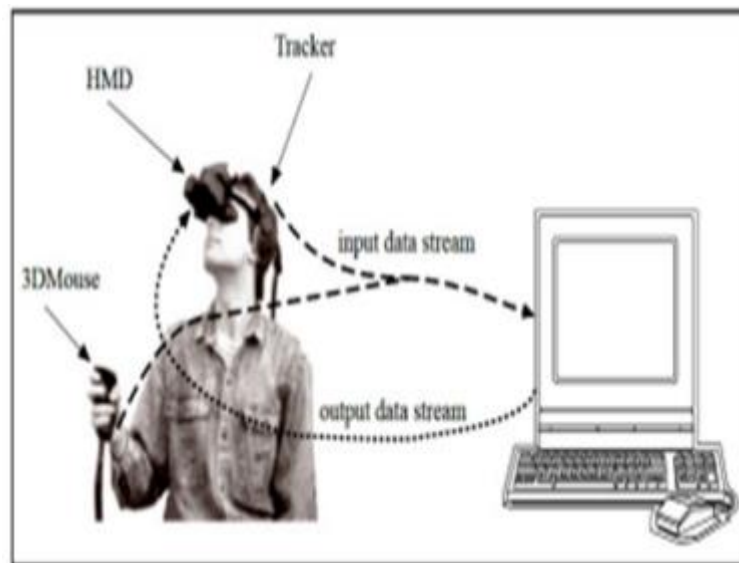
Figure 2.1: Virtual Reality System [49]

In study [50], VR is described as a computer created multisensory program that tracks the user in real environments. The research also identified three attributes of the VR system, namely imagination, interaction and immersion, which are also referred to as the 'I^3' shown in Figure 2.2.

Imagination is the creativity of the designer who designs the VR system in order to accomplish a specific goal. When compared to conventional 2D drawings, the complex designs for VR systems require more effective and well-organized design ideas to solve the problems of the virtual world. Imagination is the key attribute defined by [51] as the conquering of disbelief that is required to achieve the immersion experience in VR.

The role of the interaction is very important in managing the virtual environment and engaging the user within that environment. Interaction is the process of communication within the virtual systems [52]. In VR, the interaction can be done through hardware devices like the HMD, 3D mouse or space ball. Some of the interaction features in VR are; user participation, efficiency and real time response to the VR experience.

The term immersion is used to describe the involvement of the user in a virtual world. This shows how much users feel about being physically a part of the virtual world [53]. According to [54], immersion is the sensation of being present in the virtual environment with the effect of sensing the human stimulus (haptic, smell, touch, visual, auditory etc.) through the system.
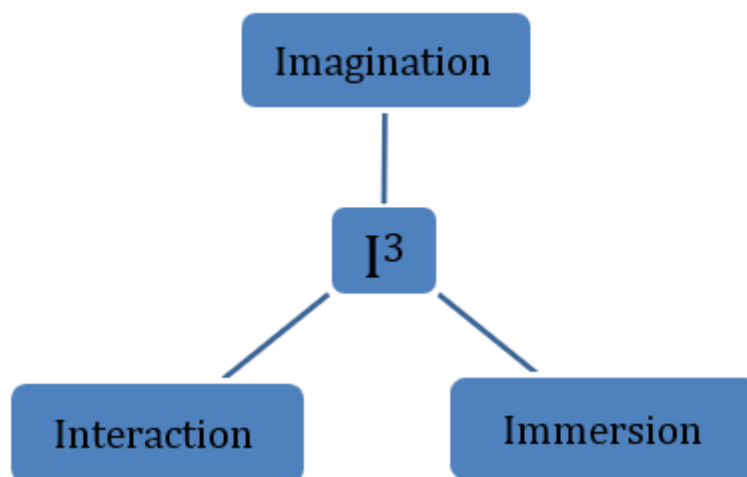
Figure 2.2: Attributes of VR (I^3)

The immersive virtual environment system is subdivided into the following three types [55] and the difference is also shown in Table 2.1.

2.3.4   Non immersive VR system

The non-immersive system is often called desktop VR, displayed on the computer screen without any input devices like the HMD [56]. This is the most extensively used system which comprises of usual computer screen to show the virtual environment. Though, this approach contains the lack of existence and sometimes interaction to the immersive world but this satisfies the quality of the graphics, ease for the user and also it is affordable in terms of cost [57].

Non immersive systems are mostly used in the field of education. It helps in the learning

process and improves the understanding level of students towards the learning material [45]. Another example of this system is the video game based on the computer screen, which integrates real world objects into computer graphics and allows interaction with objects only on the screen [58].

2.3.5 Semi immersive VR system

Semi immersive systems are also called hybrid systems that offer higher level of immersion but has simplicity of the desktop VR [45]. The semi immersive system contains attributes of both the real world and VR. It uses high performance computer graphics presented through physical displays (usually multiple screens), to create a virtual scene in real world [59] e.g. flight simulator. The user can control this system through input devices like keyboard, mouse, joystick and glasses. It also permits the user to interact through hands [58] but the user does not need to wear HMD and is still aware of the outside real world.

2.3.6 Fully immersive VR system

The fully immersion system provides the most expensive VR system with the highest level of immersion, known as neural direct virtual environment. It gives the user a feeling of being in a different world where the user has a new identity and is unaware of real world. This VR system requires the user to wear HMD and data gloves which track the head movement when user changes position [59]. The fully immersion surrounds the user with 3D computer generated simulation which gives the feeling of presence in the virtual world.

This VR system encompasses the audio and visual senses in the VR by excluding the outside information to make the involvement fully immersive. This system is so expensive including some drawbacks like burden of the hardware devices (such as HMD) on the user and simulators concerning problems [58]. The example of full immersion is the virtual walk of a building [45].

Table 2.1: Comparison between immersive VR systems

	Non-Immersive VR System	**Semi-Immersive VR System**	**Fully-Immersive VR System**
Immersion	Low	Medium	High
Interaction	Low	Medium	High
Graphic Quality	High	High	Medium
Price	Lowest Cost	Medium Cost	Very Costly

VR systems help to change the human behaviors [60] and working styles in order to achieve effectiveness in work [61]. It also offers cost and time effective solutions to many problems e.g. it provides a virtual solution for the work which is too dangerous to perform physically and has no physical alternatives as well [62]. VR has the ability to improve the quality and productivity of group relationships. There are a variety of VR applications found in different fields of our everyday life such as engineering, education, medical, video games, aviation, architectural designs, sports, different simulations used in the war and many more [63].

2.4   Role of Virtual Reality in Education

The traditional method of lecture-based systems created the problem of disengagement among the students towards their learning materials. This disengagement sometimes hinders the success of students [64]. One of the most rapidly growing form of learning in computer-based learning is the immersive environment. This new advancement in technology has changed the field of education for secondary school level and thus complements the traditional teaching methods. The study [65] defined the virtual environment for education as "an environment built on the academic model, provides the user experience which they didn't experience in the physical world, contributes to the learning outcomes and integrates didactic objectives".

Numerous features of the VR can enhance the engagement level of the students because it gives the immersive and interactive experience and offers learning in an innovative way [66]. Example for this type of engagement is 'Google Expeditions' which allows the teachers to take students to virtual trips to moon, bottom of the ocean, planets and many more. This develops interest in their subjects, enables better classroom conversation and also improves the overall participation of the students within the classroom [67].

VR may be also an opportunity to make boring subjects interesting and attractive. The study [68], found that VR increases interest level of students towards the subject of archeology, which was the least interesting subject for students before using VR. The new advancements in VR focus on the students which show less interest towards their studies and also highlight the subjects which they feel are inappropriate and boring. The increasing sense of presence in VR is the most appropriate option to gain the engagement level among the students [69].

VR also delivers constructivist learning in which students construct their own kind of knowledge from using an immersive environment. It engages the students to find out their own solution to different problems and discuss & communicate with others [70]. The VR provides the student to control the objects in order to gain the knowledge and an affordance which traditional method is unable to deliver. For example, 'Fantastic Contraption' uses the concept of constructivist learning to make students understand principles of Physics. The player builds a machine and if it doesn't work appropriately, students use their problem-solving skills to fix the problem until it works perfectly [71].

Students with disabilities, social anxiety, emotional distress and other related disorders can slow their learning process and there is also a lack of collaboration with other students [72]. VR gives the platform of therapy or training for these types of students; the virtual environment allows the student to continue their learning in a more explorative way due to which they can be more engaged and empowered [73]. The applications of VR such as 'VR Language Learning' and 'Public Speaking VR' are the examples which help the students to speak in the classroom or in the public without any fear [74].

Most of the time, student finds the classroom learning irrelevant in terms of content learned in textbooks which is different from the practical work in real world [75], this condition

is referred to as the lack of situated learning. For example, in the subjects of biology, the situated learning allows the student to learn and understand the biological terms while seeing the wider applicability instead of memorizing too much content which is also isolated from the situation [76]. VR gives an opportunity for the situated learning which is easy to access which not only increases the motivation for learning but also helps students to learn academic content which is relevant [77].

In the field of medicine, life of an individual cannot be placed in hands of a beginner, thus VR plays an essential role in educating and training medical professionals. The virtual simulations have been used more often for the model of body parts which is an inexpensive technology and easily reachable [78]. The virtual environment permits new medical students to practice without the need of any human body, cost, any ethical restrictions and resource availability [79]. This innovative technology helps in reaching out to interested secondary school students who want to pursue their higher education in medicine and these students show a high level of enjoyment and engagement [80].

In the physics classroom, a 2D computer-based simulation program called 'Interactive Physics' which helps secondary school's teachers in increasing their content knowledge and also helps in integration of this technology into their lesson plans [81]. Similarly, another simulation program called 'Real Time Relativity' has a positive outcome on the performance of students in exams, enhances student's confidence towards the understanding of course materials and also increases their interest in the subject [82].

The study [83], explains a VR program called 'Interactive Future Mathematics Classroom', can be useful for fifth grade students in order to promote the understanding and proficiency in solving geometric problems and increase familiarization with different geometric notations. This virtual program provides a table where different shapes can be added, removed and moved. It also contains a whiteboard where students can write mathematical terms or equations, make notes, communicate with other students and share their point of view with other students, this helps in solving the problems related to mathematics. The case-control study based on the virtual environment showed that after the pre and post-test, that the students using a VR application gained more understanding about geometrical concepts and learned problem-solving skills as compared to the control group.

The immersive technology also plays an important role in the subject of chemistry which involves the visualization skills to assemble the atoms so as to form the molecules [84]. The study [85] used 'Second Life' VR to enhance the chemistry concepts among the students. This program is based on a 3D virtual environment in which the students move the objects with mouse and keyboard, communicate with text and voice [86]. Two experiments were conducted among the students who used either traditional methods for learning or the VR application. The study identified that the Second Life refined students' performance, satisfaction and confidence in visualizing chemistry geometrics.

A lot of different educational institutes are now using VR to teach the students in an innovative way and to gain engagement level into their studies [87]. VR has the ability to introduce practical knowledge and make educational learning unique. VR changes traditional learning into a virtual environment. Many advantages have been identified through literature and presenting VR in education that include [88]:

1. Virtual environments are the new technology for creative learning.
2. This is a cost-effective cutting-edge technology.
3. Virtual games increase motivation among the students.
4. VR increases collaboration among the students which can also benefit their social interactions.
5. The results from the learning process through VR are accurately evaluated.

2.5   Learning in Virtual Reality Laboratory

Science laboratories play an important role in filling up the gap between practical experience and theory [89]. By definition the laboratory is defined as 'laboratories are the learning activities based on the experiments, observations, testing and investigation' [90]. Students interact with different instruments and materials to understand natural processes in the world. The traditional laboratory comprises multiple instruments, related tasks, supporting materials, learning aids (lab tutors, books) and a physical laboratory.

2.5.1 Role of Science Laboratory

A Science laboratory helps the students to grow their scientific and systematic attitude and bring out their confidence in self-directed practice tasks given to them [91]. The laboratory experiments permit students to learn by understanding and engaging themselves in productive knowledge by doing things [92]. It defines the science concepts in a more meaningful way; thus, teachers should give more work to students related to laboratories instead of theory in order to gain correct knowledge of science [93]. The study [94] described that practical and theory are not separate, theory tries to explain the observable situation where as the practical work justifies the scientific law. The science laboratories can only be benefited if students perform the number of experiments, note observations and infer some results from the practical work.

2.5.2 Learning outcomes of laboratory

The laboratories have been used for over 100 years; the teaching methods connected with them also changed over time [95]. It is also important to understand whether the teachers met their achieved learning outcomes from the use of laboratory or not. Sometimes the learning outcomes from laboratories fail to show the association among the student's learning and their practical work [18].

Some of the identified factors which affect learning of students in laboratories include [19]:

1. Lack of enthusiasm depicted by teachers while teaching.
2. Lack of guidance for laboratory experiments which result in less student engagement to the experiments.
3. Inconsistencies among the teachers that what is essential and best practice? Which experiment can affect the student's laboratory learning?
4. Limitations like lack of facilities, time, resources, lack of teacher's abilities for practical work, high cost equipment, maintenance and infrastructure.

5.   Experimental work may obstruct the understanding of scientific concepts.

2.5.3 Virtual laboratory

Virtual laboratories deliver immersive forms of a traditional laboratory. Students are provided with virtual objects which are used in the traditional laboratories. These virtual laboratories may help in learning and teaching processes, giving an environment to students in order to learn by doing different experiments and develop their interaction with other classmates [96]. It offers students to examine the situations and learn advanced concepts that cannot be experienced in physical laboratories [97]. Virtual laboratories also offer visualization to various abstract concepts in form of graphical representations [98].

Virtual laboratories save time and space, equipment is easy to assemble, instruments are more appropriately used, more time effective as compared to traditional laboratories and students can repeat the experiment [99]. It solves the issue of checking performance of the students throughout the experiments in crowded groups and also cost effective in terms of laboratory maintenance [100]. In addition, virtual laboratories can easily perform high risk experiments without any fear, which needed precautionary measures in traditional laboratories [101]. Virtual environments can be used as the instructional tool, which improves the laboratory with contextual elements; this helps students in understanding the connection between the laboratory and the real world.

2.5.4 Existing studies in context of virtual laboratory

Virtual laboratory provides an interactive environment which is used for performing virtual experiments of STEM subjects [102]. It can improve the learning process and also increase effectiveness. Teachers can easily present information and explain the course material efficiently and students can also learn technical skills through virtual laboratories [103]. It supports the educational instructions which cannot afford to build laboratories and equipment due to financial constraints.

The experiments performed in both virtual laboratory and traditional laboratory are able to increase the learning and enhance constructivism. However, according to [104], there is a difference between both the laboratories related to student's learning, for example students using traditional laboratories are attentive when working with physical instruments whereas students using virtual laboratories focus on the objects and interaction with the objects which produces learning outcomes.

Most of the virtual laboratory uses the computer screens by displaying the tools, material and laboratory equipment in front of the students and after performing the experiments it is saved on the computers, CDs or websites [105]. Virtual laboratory also offers the student-centered approach because it provides creative learning by doing different types of practical work whereas the traditional teacher-centered approach gives unsatisfactory results to student's learning [106].

Virtual laboratory also gives training to the students before they perform any experiments in a traditional laboratory [107]. This research studied the achievement level of students by using a chemistry virtual laboratory. The achievement level was measured in two environments; one is traditional and other is blended (mixture of traditional and virtual). It was found that the students in a blended environment performed better as compared to the traditional environment because they were more engaged. The author concluded that the virtual laboratory is additional tool which improves the student's learning achievement in chemistry course.

Some of the theories and concepts are difficult to perform or explain using real laboratories but they also need true observations [108]. In this situation, virtual laboratories play their part in supporting traditional practical work and provide a platform for students to perform experiments on the computers anywhere. According to [109], an application called 'PhET' is the virtual laboratory simulation which provides the virtual practical environment which is often used in the learning process. Based on the past research on traditional laboratories, this simulation helps students to understand the course concepts, gives constructive and interactive approach, take feedback and enhance the student's creative thinking.

Another example of virtual laboratory is 'Crocodile virtual laboratory' which provides the practical work of physics and chemistry on the web for students of different grades [110].

This research studied the effect of using crocodile simulation and gathered sample of 42 students from secondary school. Two groups were made; the first group used the crocodile virtual laboratory application whereas the second group used the traditional laboratory. It was found that the students in the first group performed better than the second group. The author also reported some limitations associated with crocodile application, for example teachers cannot track the student performance and lack of communication with students.

Virtual laboratories are also effective in virtual collaboration, social experiences and engagement in group discussions. The study [111], uses 'Maroon-The Immersive Physics Laboratory' as a tool to increase the motivation level of using virtual laboratories among the students. Maroon is the 3D physics laboratory which simulates and illustrates different physical situations. It is used with room scale VR with HTC Vive. HTC Vive helps the user to move into the immersive space and interact with virtual objects through motion track controllers. The author concluded that the room scale-based experiments were much immersive and engaging when compared to traditional based laboratory experiments. The participants also mentioned that it was a realistic and interactive environment, they were also able to explain the experiment easily in a small quiz. Thus, this setup was experienced as more collaborative, engaging and immersive as compared to all other setups. Though, this setup has also some limitations like it is expensive and difficult to install.

In study [34], the author developed a virtual laboratory application called 'Water Cycle in Nature', a 3D immersive computer based small scale research study which was carried out in primary school in Ireland. This pilot research focused on physics practical work such as evaporation, vaporization and condensation and 58 students of primary school participated in this study. The main focus of this research was to examine learning experience of the students and usability of the developed application. The results showed that the application was effective and students also enjoyed it while performing experiments. However, this study is limited to students with hearing impairment and it was conducted within a small-scale primary school.

Physics is the most important subject of STEM education which contains some challenges for students to understand the physics concepts. According to [112], the author described virtual laboratories as an innovative learning environment that helped students understand physics course topics efficiently. The study used a 3D virtual laboratory application

in which students explored the experiments and a deeper cognition of how to perform virtual experiments. The virtual agents of pedagogy were also included in this research, who helped and gave training to students in virtual laboratory.

The researcher in [113], investigated learning among the students through game-based application which was developed in VR and Augmented Reality (AR) for chemistry experiments. The purpose of this study was to explore the effectiveness of learning, game acceptance and a flow through user study. The results showed that this immersive technology improved learning in chemistry experiments with student's acceptance and involvement in the application. This study is limited to the control group and investigates user behavior in an integrated environment.

2.6   Key Learning Parameters of Secondary School Education

Learning is the activity of an individual and differences among individuals do exist throughout this activity [114]. Learners are different from each other; they can learn effectively if a learning environment fulfils their needs through understanding characteristics of each individual in the learning process. For example, in secondary school's education, some students quickly understand the course concepts while other students need time and may require repetition of a lesson to fully understand the topic [115]. Similarly, some students learn through visual representation (e.g. pictures) of a lesson because pictures attract the attention of students whereas others are comfortable in verbal methods of learning [116].

In secondary schools, students have different types of needs, methods and preferences in the process of learning. According to [117], there are different categories of learning parameters that affect the student's learning in secondary education which includes:

2.6.1 Affection

Affection is a positive feature in which teachers can care and guide students in the teaching-learning process [118]. It is the expression of a teacher for their students. Thus, students feel comfortable and show desire for study. The affective relationship between teacher and student has a great impact on student's social interaction and success at school. Affection can be further divided into subcategories [117].

Difficulty level of learning materials: The difficulty level of a test is the way to determine the student's understanding through learning material obtained from the class. The test score gives precise information on how far students understood the teaching-learning process [119].

Technology Acceptance: Technology acceptance is defined as the user's willingness to accept and adopt a technology when performing certain tasks. Teachers are guided to use technology into their classroom, they spend much of their time in planning on how technology could be utilized as an effective delivery of lesson [120].

Learning Styles / Preference: Preference or style is all about how the students learn. They learn in different learning styles or preferences, which helps in gaining new skills and knowledge. A student's learning depends upon the learning style they prefer. Some students like to listen whereas others prefer to read or watch and some might want to practice [121].

Learning Perspective: The main purpose of learning perspective is to focus on the relationship between student behavior and environment. It explains how students learn through the idea of associationism, which means that students associate and build connections between events and ideas in the process of learning [122].

Learning Motivation: Learning motivation is the student's objective or aspiration to achieve certain goals. It has been shown that motivated students are more engaged, determined to reach their goals, perform better than non-motivated students and show higher learning outcomes [123].

Learning Effectiveness: Learning effectiveness can be measured from the rate of course completion, time spent on learning, perception of the students and how learning transfers into productivity [124]. To improve learning effectiveness, it's necessary to enhance learning motivation first and then participate actively in the learning process [125].

Learning Attitude: Learning attitude is liking or disliking a particular subject. Mostly, the attitude factors cause poor performance in STEM related subjects. It changes the response of students either positively or negatively towards the subject, teacher, situation and concept. Positive attitudes enhance student learning and negative attitudes may hinder the effectiveness of student learning [126].

Self-Confidence: Self-confidence is a student's belief in their ability to do well in the learning process and willingness to face risks. Students who lack self-confidence cannot achieve success in their studies. Self-confidence can be shown through behavior, body language, what and how you speak [127].

Satisfaction: Student satisfaction is a sign of whether students are satisfied with their learning experiences. Students achieve learning satisfaction through team work, e-learning courses, team performance and collaborative learning [128].

Cognitive Load: Cognitive load is the amount of load placed on a student memory from different learning materials. Poorly designed learning materials can increase cognitive load. Due to this, the effectiveness and efficiency of learning also decreases [129].

2.6.2 Cognition

A mental process which involves gaining knowledge is referred to as cognition. Cognition is a field of psychology and possesses the higher levels of brain functions. It impacts every situation like from school to work and to relationships. In the education field cognition focuses on how students think and learn new concepts [130]. There are three sub categories, which includes [117]:

Learning Achievements: A change which is achieved by someone after the learning is known as learning achievement. This change includes change in skills, knowledge and attitude. Students can achieve their success through test scores obtained from a particular subject. This score indicates how far students are able to understand the topic of a specific subject [131].

Collaboration: Collaboration is also one of the learning strategies which can be achieved by making groups of two to five students. Through this strategy, students gain knowledge from each other. For effective learning, teachers should organize different activities into groups so that students learn from their collaboration [132].

Thinking Level: Creative thinking is the ability to think of possibilities and use different methods to solve a problem. It should be practiced in education at all levels from school to university in order to achieve student objectives. There are five levels of thinking which are level 4 (very creative), level 3 (creative), level 2 (quiet creative), level 1(almost not creative), level 0 (not creative). Through this, the creative thinking skills of students are measured [133].

2.6.3   Behavior

Behavior learning is a behavior that can be learned and changed through reinforcement either negative or positive. In the classroom environment, behavior can help students and to motivate them. Teachers provide information or knowledge as a stimulus to students and show how students respond and react to particular stimuli. Positive reinforcement is important in behavior learning, without this student suddenly leave their responses. For example, a student receives complimentary remarks (positive reinforcement) from the teacher when they scored good marks on a test. But if teachers stop giving remarks then fewer students get good marks because their behavior is not connected to the reward [134].

2.6.4 Learning Skills

The tasks involved in learning like reading, time management, taking notes and tests from learned topics are described as learning skills. Nowadays middle and high school teachers teach students with 21st century skills as a part of the curriculum. In the 21st century skills, educators prepare students to face the demands of life which includes: problem solving skills (an activity where students choose their way out of the situation by using their rational abilities and become a problem solver), creative thinking skills (empowers students to see concepts from different angles and ends with some innovation) and cognitive abilities (learn from experiences) [135].

2.6.5 Correlation

Correlation is a relationship between learning approaches and the academic achievements of a student. It is used to measure the performance of students and to give a better idea of a student's capacity for learning. There are three types of correlation: positive, negative and zero correlation. In positive correlation two variables move in the same direction which means if teachers use the good approach for teaching then student's performance also increases. In the negative correlation, both variables move in opposite directions and there is no relationship between variables with zero correlation [136].

2.7   Design Guidelines of Virtual Reality

The technology of VR is gaining popularity day by day in every field, yet it lacks good design practices and methods when designing VR applications [137]. For this reason, user experience (UX) plays an important role in designing VR applications so that users can interact with the application easily. UX is defined as the quality of interactive technology, which means it focuses on humans and not on product [138]. UX is also referred to as product simplicity along with elegance which users enjoy while using the product. It is also an emotion that users experience when using a service, application or product [139].

The key element of UX which assures its quality is the usability [140]. Usability is a study of the interaction between a user and a system, as well as expectation and tasks. The ISO Standard (ISO 1988) defined usability as "a specified user achieves their goals in terms of effectiveness, efficiency and satisfaction when using a specified product or system" [141]. Another concept that improves the system's UX and helps users interact with the system is affordance [142]. Affordance is subdivided into four types which are sensory, physical, cognitive and functional affordance. Sensory affordance supports users with actions like hear, see and feel. However, physical affordance helps in physical actions such as touch, click and point. Cognitive affordance helps users in actions like, thinking, remembering and learning. Whereas, functional affordance helps users to easily use the system [143].

There are different design guidelines or principles that assist the designers when designing 3D interactions and VR applications. Some of the guidelines identified are [144] [145] [146]:

2.7.1 Minimum Degrees of Freedom (DOF)

The 2D controls are comparatively easier to handle than 3D and most users have no skill with 3D controls. That is why, it is important to understand the interaction techniques and design space when designing 3D environments. According to study [144], creating 2D controls in 3D interactions is an alternative way to increase usability. If an input is assigned to a high DOF task but it actually requires low DOF, then the task is difficult to perform. For example, when a user wants to click on a menu or button which is normally in 2D, but the application needs to select a menu or click on a button with a virtual hand or another 3D input control. This slows down the user interaction with the application and leads to user frustration. Therefore, the author [144] suggests using mouse or pen-based input devices for such scenarios. Further, he recommends that the user interface should be simple, in this way users can easily interact with the application.

2.7.2   Preventing Sickness

The user's first impression is really important for experiencing a VR application for the first time. The following are the guidelines for preventing sickness when using the application.

Average Use of Brightness: It is hard for some users to adjust in VR from the real world which can cause VR sickness. This can be reduced by applying fades at the start and end of application. Fade can be done by adjusting saturation, contrast and transitioning to black or dark colors. Sometimes transitioning causes discomfort and takes time for eyes to adjust in different colors when moving from bright to dark scenes or vice versa. There is a need to adopt moderation in bright colors when designing such applications because increased light tired out eyes [147].

Minimize Acceleration: Acceleration or motion is also one of the major causes of VR sickness for those users who never experienced the immersive environment. The applications based on moving platforms like car simulators are prone to motion sickness [148]. This sickness occurs because of how the eyes and ears see and detect. It can be reduced by lowering the resolution or by adding blur, this increases the sensation of reality and brings down motion sickness. There is another recommendation to indicate the users before start of motion and encouraging new users to begin with slow motion [149].

Minimize the Use of Images: The images with fine textures and strips are spatial images which increase the feeling of motion. The use of such images should be minimized. Some applications use flashing light which irritates user eyes, this can also be avoided when designing VR applications [146].

2.7.3   Creating Depth Cues

The natural depth cues are limited in VR applications for this reason some depth cues can be recreated in order to generate the sense of a three-dimensional scene. These depth cues

include relative size, occlusion, atmospheric perspective, shadows, motion parallax, texture gradients and linear perspective [150].

2.7.4 Correct Placement of User Interface Elements

The User Interface (UI) elements should be placed in a comfortable distance from the user. These elements (e.g. tools and text) can cause an eye strain when it places too close to the user [146]. Use images, text and other objects in application so that it looks natural when the user looks around. Mostly in VR applications, the text is difficult to read. It should be big enough to be readable. The UI elements should be available at a specific position of every scene so the user can easily access them. Make a UI design in such a way that it encourages users to explore and interact with the application [151].

2.7.5 Use Guides or Cues to Get Started

Most of the new users do not know about VR and they have no idea where to start from. They need some help to get started and move around the space. Using guides or cues such as images, sound, popups and light helps users how to do work and where to move in the 3D environment [152].

2.7.6 Make Easy to Remember Controls

It is difficult for new users to remember a lot of controls in a VR application because some users have limited memory. There is a rule of thumb that one human only remembers 7 plus or minus 2 chunks of information [153]. Thus, the number of buttons and controls should be minimum so users can easily remember and learn them [154].

2.7.7   Use Existing Knowledge of Real-World Objects

Physical objects have a lot of meaning and affordance, using these objects to explain to the user how things work and build interest for the experience. When given the full physical affordance, the user knows what they can do in 3D environments. Materials, shape, color and placement of objects in a VR world helps users to interact with them [146].

2.7.8   Use Gestalt Principles

It is important to keep in mind the principles of Gestalt like similarity, hierarchy and proximity when designing VR applications. This helps the users to select controls or objects correctly and quickly. The items in an application should be scaled properly and well-spaced so that the user can select a correct item without selecting nearby targets [155].

2.7.9   Give Immediate Feedback

The user should receive immediate feedback after interacting with objects, in the form of text, audio and haptic. These feedbacks let users know whether their interaction with the object was successful and whether they performed the task correctly [21].

2.7.10   Use Background Audio

The audio plays an important part which helps users to determine their environment in the real world. From the sounds of crowded streets to the buzz of a bee and noise in the office to the echoing silence in a cave, background audio cues are enough to describe the environment. Audio provides user attention to the surrounding environment. Just like the audio triggering can be considered when interacting with VR objects, the background audio also plays a role in experiencing VR [156].

2.8: Summary

This chapter thoroughly reviewed the area of traditional teaching methods and highlights the benefits and drawbacks when using this approach for learning. The chapter covers the topic of virtual reality and its working, which is now used in every walk of life like medicine, education, e-commerce, traveling, business, engineering, gaming etc. Virtual laboratories overthrow the traditional laboratories with their inexpensive immersive environments. This also overcomes the educational issues like time and cost, students with no or less interest related to their course, sometimes teachers are unable to deliver quality education, no funding for infrastructure and expensive laboratory equipment. These immersive environments are beneficial in terms of time and cost, enhances the motivation and engagement level among students, increases creative thinking and also effective for learning outcomes. This chapter also identified the learning parameters of education which can affect the learning of students in secondary schools which includes affection, cognition, behavior, learning skills and correlation. There is also a need for design guidelines for designing VR applications, for this reason user experience plays a huge part in helping users to interact easily with the system.

CHAPTER 3

METHODOLOGY

3.1   Overview

This chapter explains methodological aspects (section 3.2) of the research in terms of literature review, application development and user study. It also includes selected mode of data analysis on data collection (section 3.3) which helped in analyzing the effectiveness of students learning through virtual laboratory.

3.2   Research Methods

The research methods chosen for this study consisted of literature review followed by a quantitative research approach. A literature review can be described as a way of gathering and synthesizing prior research. An organized and effective review used as a research approach which builds a strong foundation for promoting knowledge and advancing development of the theory [157]. A quantitative approach investigates the situation through collection of numeric data by applying mathematical, statistical and computational techniques on the data [158]. In this study the primary method was used which is also a part of quantitative research approach [159].

3.2.1   Literature Review

In first phase, the literature review was conducted. Literature review is an efficient way of collecting and synthesizing previous studies [160]. It considered as the best methodological

method to answer the research questions [161]. Literature reviews are useful for evaluating information on a specific topic. It can also be used to find gaps or even just to discuss particular areas [162]. This research thoroughly reviewed literature for key learning parameters of secondary school's students and the design guidelines for virtual reality. The purpose of these identifications was to determine student's learning achievements by applying parameters and guidelines to the virtual laboratory application. Many learning categories and design principles were explored from different studies which supported in the development of an application.

3.2.2 Application Development

In educational institutes, the use of 3D environments is now becoming attractive for students because of their user-friendly interfaces, rich in graphical presentation and adaptive abilities [163]. The developed application in this study helped science laboratories in schools to move from physical existence to virtual environment. Through this transformation, the expensive instruments used in traditional science laboratories converted into graphical virtual objects which are not only easy to use and move but also perform faster. The developed application runs on low cost technical equipment such as computers and software which are cheaper than equipment used in traditional science laboratories [164]. It provides the students with a safe and interactive environment in which they perform experiments within groups or individually.

a)   Application Features

The main purpose of the virtual laboratory was to provide a real laboratory-like environment for students so that they can perform experiments without hesitation and also repeat them. The application was developed for a STEM subject physics. It was a 3D virtual environment (Figure 3.1), specifically designed for secondary school students. The reason for choosing a physics subject was because students usually get bored while performing physics experiments and pay less attention to the subject [165]. This application was designed to be a fun and engaging environment so students would be attracted to it.

Figure 3.1: Virtual Laboratory Application Environment

Sign Up/Sign In: Once, students started the virtual laboratory environment, they showed up at a signup screen to register themselves into an application. This was necessary to access the virtual physics laboratory. Each student created their account in a virtual environment by entering basic information like their full name, username and password. After a successful signup, students were allowed to login to the application by clicking a login button.

3D Virtual Laboratory Environment: After login, the students entered into the virtual laboratory environment. There were four different work stations for each experiment and each station had different tools placed on the shelf. This 3D virtual environment was interactive and easy for students to use and move around the laboratory.

Selection of Experiment: The students were able to select an experiment by visiting each workstation in the laboratory. When a student was approached at the desired workstation, a message popped up briefly explaining the selected experiment with an
enter button. Students were also able to select a particular experiment from a list displayed on a right side of the main screen.

Performing the Experiment: The interface was designed in such a way that students did not face any difficulty while performing the experiments. At the start of every experiment, there

was a user guide that helped students to perform the experiment in a correct way. Each workstation had the facility to drag and drop tools or instruments used in experiments. After performing experiments, each student entered their readings which were then stored into a database and sent to the demonstrators. The demonstrators evaluated each student's performance in a virtual physics laboratory. They also assessed student scores and the accuracy of experiments performed. If students weren't getting their desired results, they could repeat the experiment.

Experiment Details: The practical notebook for each experiment was also available in a laboratory environment. It helped those students who didn't know about the selected experiment or they wanted to clear their concepts. The students read practical details of each experiment by clicking on a practical notebook button displayed on the right side of the screen.

b)   Application Setup

The application setup contained hardware and software. The hardware included computers and laptops while for software, unity 3D was used to construct the virtual environment. Unity 3D is a cross platform for games with the facility of built in IDE which is developed by Unity Technology [166]. The workstations designed for all four experiments and the tools or instruments used in them were built on Blender software. It is mostly used for the designing of shapes, objects, 2D and 3D models, visual effects, fog simulation, user interface for games and for animation [167]. After designing the experiment's objects in Blender, they were then imported into Unity 3D and integrated into the virtual environment. The 3D model was controlled and interacted using the scripts, coded with C# language. These scripts were written using MonoDevelop which is an editor for various languages [168]. PHP and MySQL were also used for saving the records, including account information, readings and marks of each student after performing experiments.

c)   Experiments Included in Application

The environment of a virtual laboratory was designed in such a way that it should mimic a real laboratory, consisting of workstations, charts, instruments/apparatus, practical notebook, tables, benches, clock, shelfs, door and windows. The application contained four physics laboratory experiments that were included in the secondary school curriculum: Vernier Calipers, Coefficient of Sliding Friction, Acceleration of the Rolling Ball and Value of G using the Free Fall Method. The details of these experiments are given below:

i.   *Vernier Calipers*

Vernier Caliper was the first experiment of a virtual laboratory. It is mainly used for measuring the distance between two sides of an object [169]. The object could be a small spherical and cylindrical body. The parts of a Vernier Calipers consist of a main scale which is made up of a steel metallic strip in which numbers in centimeters graduated on top and inches on bottom. The other scale is known as a Vernier scale which slides on a main scale, it can be fixed at any point through the screw on top. Vernier Caliper also carries two measuring jaws inner (used to measure inner dimension of object) and outer (used to measure outer dimension of object). When two jaws are closed, the zero of both main scale and Vernier scale should meet. If both zero's do not coincide, there will be the occurrence of positive or negative error [170].

The Vernier Caliper experiment in a virtual laboratory (Figure 3.2) designed on the basis of a real device. Same main and Vernier scales were used for measuring the objects. First, the student had to open a Vernier scale by sliding it to right from the Vernier slider on bottom. Then they had to select an object placed on the shelf such as a cylinder or spherical ball, which was placed automatically to the right position. In order to measure a specific object, the Vernier scale was dragged towards left until an object fit between jaws. Students were able to zoom in on scale readings through a zoom slider and also moved the camera to either left or right according to their needs. After performing the experiment, students entered their readings into text fields on the right side of a screen. Students were then submitted their readings to be stored in a database.
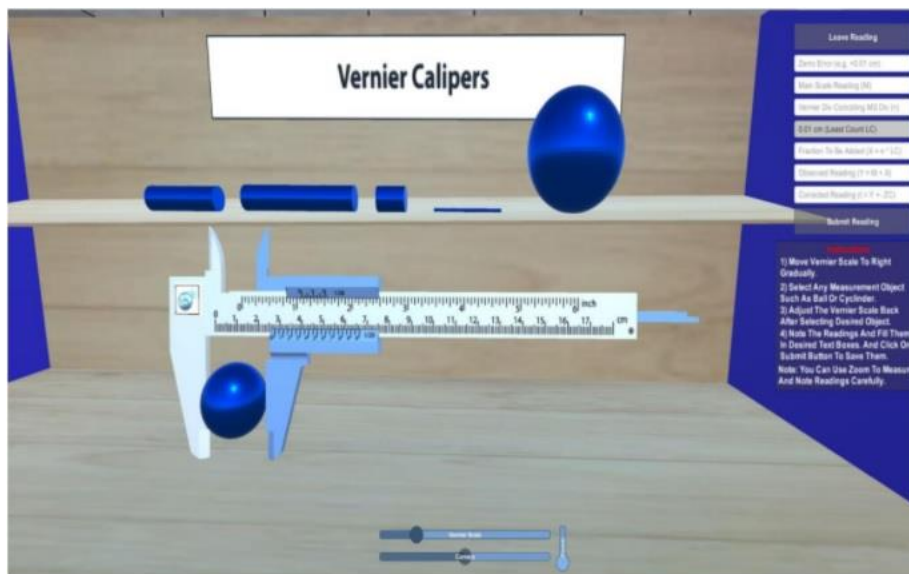
Figure 3.2: Vernier Caliper

ii.   *Coefficient of Sliding Friction*

Coefficient of sliding friction was the second experiment in a virtual laboratory. Friction is defined as a resistance which is encountered by an object when it slides over a surface. This friction is also known as kinetic friction. The friction increases when a normal force which acts on a body is also increased. It obtains its maximum value just before the object slides on a surface. This frictional force acts parallel on the surface and in direction of a moving object. Some examples of sliding friction are: skis slide over the snow surface and box slides on the floor [171].

This experiment in a virtual laboratory aimed to find the coefficient of sliding friction between a wooden block and horizontal surface (Figure 3.3). This included materials already used in a physical laboratory such as a wooden block, wood surface along with pulley, weight, thread, pan and spring balance. Instructions for performing an experiment were given on the right side of a screen. The weights of wooden block and a pan were predefined with 20g and 75g respectively. Students started the experiment by selecting a weight for a wooden block. The selected weight was automatically added to the block as shown in fig. The student had to enter a weight value for a wooden block into a text field on the right side of a screen. By clicking on the next button, the student was able to select a weight for the pan. The selected weight value

was then entered into a text field for a pan. Once the readings were done, the results were saved in the database after clicking on the submit button. The values for coefficients of sliding friction were also calculated automatically.
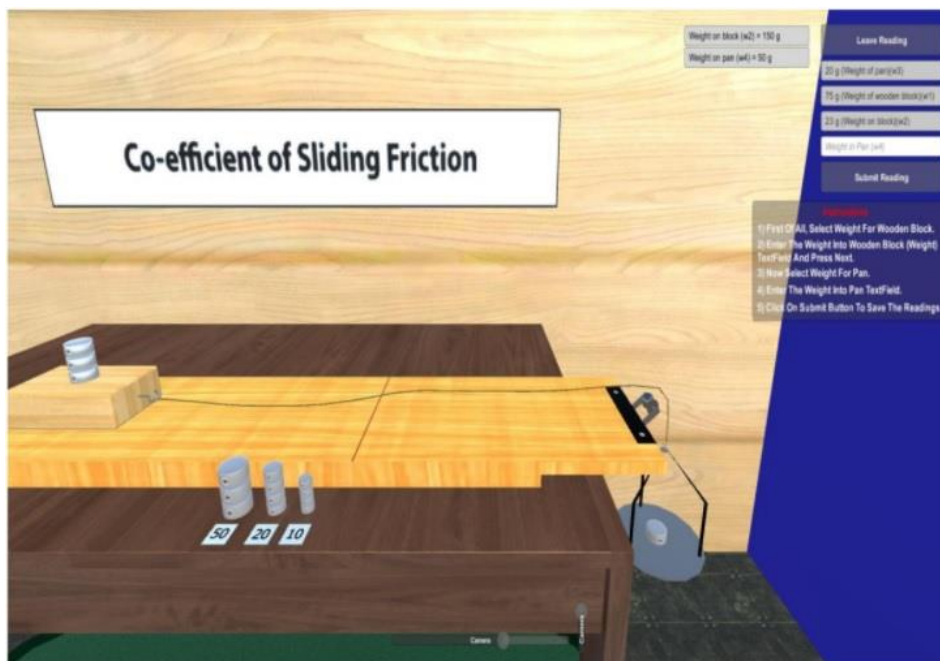
Figure 3.3: Coefficient of sliding friction

iii.   Acceleration of the Rolling Ball

Acceleration of a rolling ball on an inclined plane was the third experiment of a virtual laboratory. The experiment performed in physical laboratories and objectives of this experiment is to find acceleration and velocity of a rolling ball without slipping on an inclined plane. The experiment is based on four variables which includes; distance along the inclined plane on which a ball rolls, steepness of the incline, height from which a ball is released and time required to cover a certain distance on the inclined plane [172]. The equipment used for this experiment are a metal ball, inclined plane, stopwatch and measuring scale.
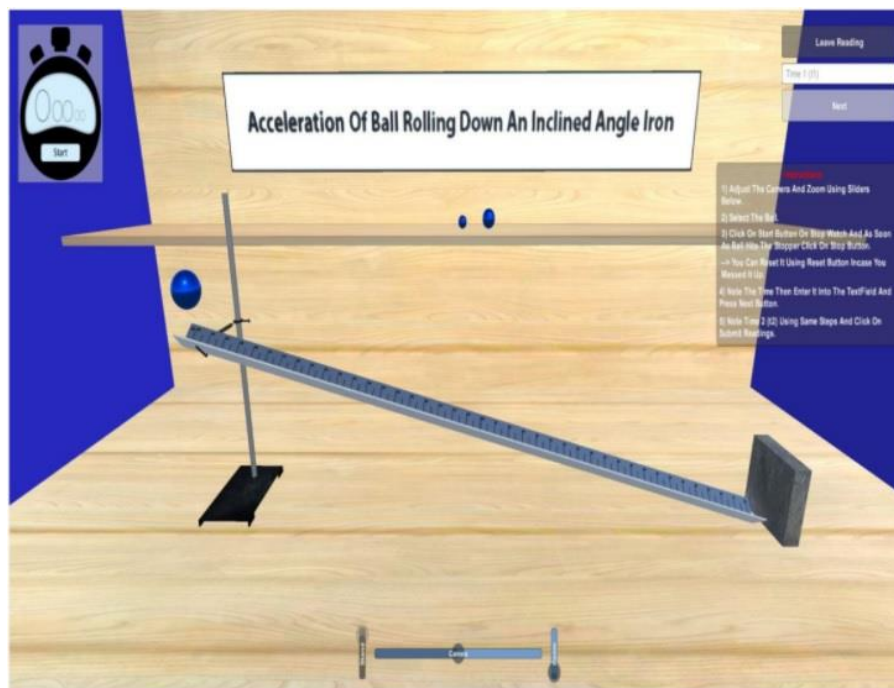
Figure 3.4: Acceleration of the Rolling Ball

This experiment was designed in a virtual laboratory like in the physical laboratory (Figure 3.4). Instructions were given on the right side of a screen and students were also given access to open the practical book if they faced any difficulty performing experiments. Students started this experiment by adjusting a stand vertically according to their needs through a stand slider on the bottom of a screen. On the shelf, there were three different size balls, 2cm, 4cm and 6cm respectively. Students had to pick one of the balls by clicking on it, which was then adjusted to fit on top of the inclined plane. The student had to take two readings of the time. The ball was released by clicking on a Start button on stopwatch which was displayed on the left side of a screen. When a ball hits a block at the end of an inclined plane, the stopwatch must be stopped by clicking on the Stop button on it. The observed reading of time was entered into a text field on the right side of a screen. The same process repeated for the second reading of time. After entering values, students clicked on a save button to store values into a database and the acceleration rate was automatically calculated.

iv.   *Value of G by Free Fall Method*

This experiment was the fourth practical activity of a virtual laboratory. The main aim of this experiment is to examine the laws of free fall and to find a value of g by free fall method. The acceleration of an object through free fall method is caused by the gravitational force of a body which is known as gravitational acceleration and denoted by g. The value of g depends on mass and size of a body [173]. Its value also varies from body to body. The equipment used in a physical laboratory are; measuring scale or meter rod, free fall apparatus, thread, match box and stopwatch.
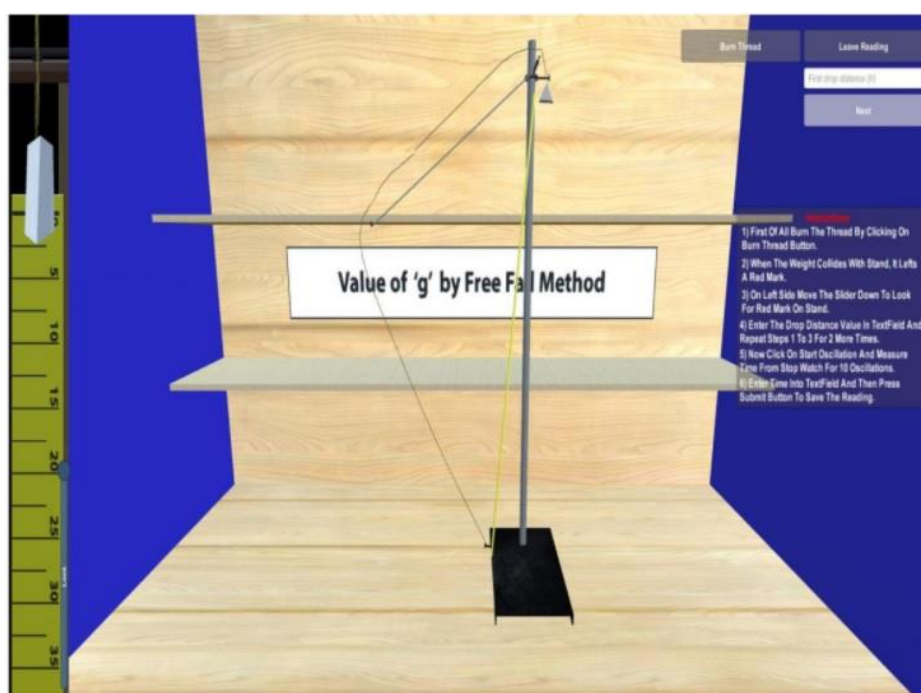
Figure 3.5: Value of G by Free Fall Method

The experiment was designed using an apparatus originally used in physical laboratories (Figure 3.5). Students started this experiment by reading the instructions on a screen. The object was first released from its resting place by burning thread, this was done by clicking on a Burn Thread button on the left side of a screen. After the thread was burnt, the object collided with a meter rod and left a red mark on it. Students were able to read a red mark on a meter rod on the left side of a screen by moving the slider downward. The reading of a red mark was entered in a text field on the right of a screen. The readings were taken two more times by following the

same process. When object drop distance readings were completed, the student began oscillating a stand by clicking on a Start Oscillation button and measured 10 oscillations from the stopwatch. The values were then entered into a text field and stored in the database by clicking on a submit button. It automatically calculates the value of g.

3.2.3   User Study

The study collected data by adopting a user study approach [16][174]. A user study is a process of understanding the behavior of a user through their observations or feedback on certain matters [175]. This research approach consists of two groups one is called an experimental group and the other one is a control group. The experimental group is exposed to changes in the independent variables being tested and researchers are interested in this effect. Whereas, control groups cannot influence the results when an independent variable is being tested [176]. Once the research is complete, data from both groups can be compared for results.

This study also comprised two groups, experimental and control. Experimental group used technology which was a developed virtual laboratory application and the control group used a physical laboratory. The study was conducted over a period of two weeks. In the first stage, students, laboratories in schools and teaching approaches were observed. Second stage involved participants sampling for two groups and introduction to a virtual laboratory application used by experimental group students. Both groups were given the same experiments and were also taught about them before starting their tasks. The third stage collected data in the form of a quiz from the two groups for evaluation (Figure 3.6). This was helpful for assessing the achievement of learning skills among the participants. The questionnaire was circulated to test the usability of using a virtual laboratory.
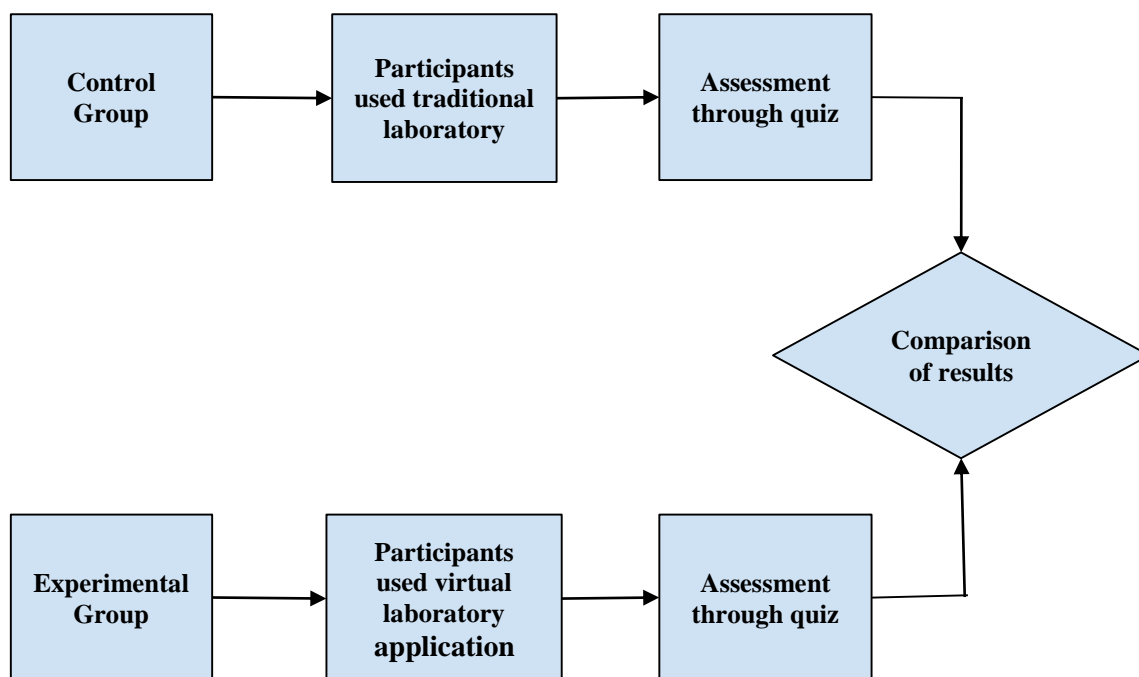
Figure 3.6: Students Learning Assessment Approach

Independent Variables: A variable which can change or manipulate and it has a direct effect on dependent variables is known as an independent variable [177]. In this study, the independent variable was physical and virtual laboratory environments for a Physics subject.

Dependent Variables: A dependent variable can be observed and measured in an experiment and it also depends on an independent variable [177]. The study consisted of a dependent variable which was student learning achievement towards Physics concepts.

The flowchart of the methodology adopted is shown in Figure 3.7.
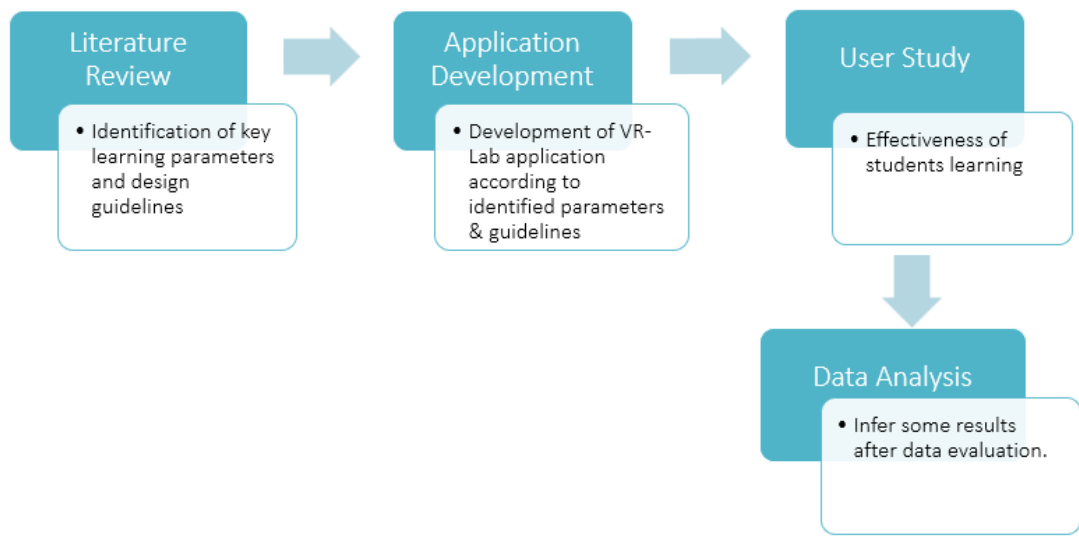
Figure 3.7: Research Methodology

a)   Area of Study

The study was conducted in four schools located in two cities which were Rawalakot and Rawalpindi. There were three schools in Rawalakot and one school in Rawalpindi. All schools also met the inclusion criteria which was already set at the start of research. The first criterion was to pick the types of institutions that were lacking in providing laboratory facilities to the students. The other criterion was to choose educational institutions whose practical work had not yet begun and students who had little or no knowledge of the experiments.

b)   Participants

In the present study, participants were aged between 14 to 16 years and from secondary schools were selected. This degree level was chosen because most students at this level show less interest in STEM subjects like physics. The total participants selected from four schools were 184 (Table 3.1) out of which 85 (46%) were girls and 99 (53%) were boys (Figure 3.8). All participants were assigned to the control and experimental groups using random sampling. Each school contained one control group and one experimental group with equal numbers of students in each group.

Table 3.1: Participants Detail

Schools	Total No. of Students	Gender		Age
		Boys	**Girls**	
School 1	54	31	23	14-16
School 2	46	25	21	14-15
School 3	44	17	27	14-16
School 4	40	26	14	15-16

The study was also observed with some ethical considerations before and during the research process. The permission from authorities of each school was granted before visiting them. Participants of each group were invited on the basis of voluntarily and confidentiality of personal data was also maintained. Furthermore, the research was conducted during a school timing and within three working days in each school. Both groups learned and performed experiments within two hours of time.
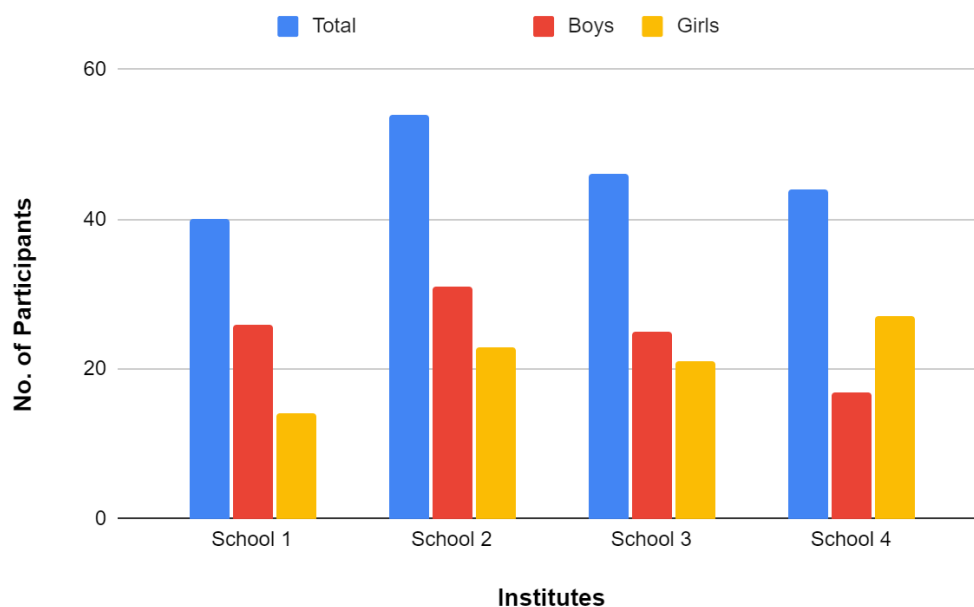
Figure 3.8: Comparison between no. of participants

i.   Control Groups

There were four control groups from four selected schools, each with different numbers of participants (Table 3.2). The control group of school 1 consisted of 20 participants, school 2 with 27 participants, school 3 contained 23 participants and school 4 included 22 participants. The teaching methods for students of control groups were traditional. The lectures in laboratories were imparted verbally, face to face and delivered using the blackboard or whiteboard in laboratories. The student's queries were also considered in person.

Table 3.2: Participants distribution in each group

Schools	Groups	
	Control (Traditional Laboratory)	**Experimental (Virtual Laboratory)**
School 1	27	27
School 2	23	23
School 3	22	22
School 4	20	20

ii.   Experimental Groups

There were also four experimental groups from four schools. The number of participants of school 1, 2, 3 and 4 were 20, 27, 23 and 22 respectively (Table 3.2). The virtual laboratory application was used as a teaching approach and as an alternative to traditional teaching methods. The participants had access to perform experiments efficiently and if they didn't get the desired results, they could repeat the specific experiment. In this way, participants from the experimental group had a better chance of learning than the participants in control groups.

c)   Data Collection

Data collection is the most important step of research. The procedure of collecting data, measuring and analyzing precise insights from research with the help of standard validation techniques [178]. There are different approaches for data collection for different fields, depending upon the information. In this study, data was collected from a well-designed quiz and questionnaire.

i.   *Assessment through quiz*

All participants from four control groups and four experimental groups first performed experiments in virtual and traditional laboratories. After completion of tasks, each participant's performance was evaluated through the small quiz. It was designed on the topics of Physics which was also used in experiments. The quiz was same for both groups because similar experiments were used in both laboratories. There were 10 multiple choice questions, each with four options from which participants had to choose one answer. The quiz also included participant's personal data such as name, age, gender and class details. The purpose of carrying out the quiz was to compare understandings of physics concepts among participants in both laboratories. The study also considered review of an expert. The virtual laboratory experiments and a quiz were validated by two physics teachers and changes were made to the suggestions.

ii.   *Usability Questionnaire*

This research also consisted of a questionnaire, which was used to obtain data from the participants to measure their learning experience in a virtual laboratory. The questionnaires are a practical approach and results can be quantifiable quickly in contrast with other quantitative approaches [179]. The questionnaire used closed ended format, it allowed participants to select only one option. It provided a fixed set of options for the calculation of statistical data and percentages. These closed ended questions supported the opinion of participants about a developed virtual laboratory application.

The usability questionnaire used in data collection was the System Usability Scale (SUS) questionnaire. SUS is the most famous standardized questionnaire and a reliable tool, used to access usability and learnability of the software, websites and applications [180]. The benefits of using SUS is that it is cheaper, has a short questionnaire with easy to manage participants, it is fast to meet large sample sizes and there is no need to research or design a new questionnaire [181]. The SUS is made up on three characteristics which are effectiveness, efficiency and satisfaction. The effectiveness is used to answer whether the user successfully achieved their goals. The efficiency measures effort and resources in achieving those goals. Satisfaction measures the user's level of comfort when experiencing product or service [182].

The SUS questionnaire consisted of 10 questions in total with two user factors or sub scale which was usability and learnability. These sub scales involved eight usability and two learnability items [183]. The participants, using a SUS questionnaire, had to answer these items on a five-point Likert scale (i.e., 1 to 5 from strongly disagree to strongly agree). The items with higher scale indicate agreement to the item. There were also slight changes made such as the word 'system' being replaced with 'virtual laboratory' and 'cumbersome' being replaced with 'awkward'. Items with odd numbers were positive ones and even numbers items were negative ones. The basic information of participants was also included like, name, gender, age and class details on top of questionnaire.

Cronbach's Alpha was used to measure internal consistency among the items of questionnaire. This was considered to measure the scale of reliability. If the value is closer to 1 then the scale has higher internal consistency [183]. Through formula, Cronbach's Alpha was measured as 0.76 which meant that the questionnaire was suitable for present study with higher internal consistency.

3.3   Data Analysis

The collected data from quiz and questionnaire were analyzed by applying statistical techniques. The techniques like descriptive and inferential statistics methods used to describe and evaluate data. Descriptive analysis used methods of mean, variance and standard deviation. For inferential analysis, z-test was performed to analyze the data. The z-test method was used

to assess whether means of the two groups (i.e., experimental and control) were statistically different [184].

In this study, the magnitude of two groups i.e., control and experimental, was measured through Effect Size. It is a quantitative measure and relationship between two variables considered best when the effect size is large [185]. In order to measure effect size, the Equation 3.1 was used.

$$\text{Effect Size} = \frac{\text{mean of experimental group} - \text{mean of control group}}{\text{standard deviation of control group}} \quad (3.1)$$

The SUS questionnaire score was calculated in a way that each response was assigned with a value or score. The strongly disagree was assigned with 1 point, disagree with 2 points, neutral with 3 points, agree with 4 points and 5 points for strongly agree. After completion of a questionnaire by an experimental group, responses from participants and relative scores for each response were calculated using the following SUS framework [186]:

- All scores of odd numbered items were added and subtracted 5 (minus 1 from each item) from the total score (Equation 3.2).
- All scores of odd numbered items were added and subtracted 25 (minus 5 from each item) from the total score (Equation 3.3).
- Both total scores (odd and even numbered) were added and then multiplied it by 2.5 (Equation 3.3).

This can be expressed in the equation form:

X = (Sum of scores of odd numbered items) – 5   (3.2)

Y = (Sum of scores of even numbered items) – 25   (3.3)

SUS Score = (X + Y) x 2.5   (3.4)

Whereas odd numbered items were 1, 3, 5, 7, 9 and even numbered items were 2, 4, 6, 8, 10.

3.4   Summary

This chapter discussed in detail the description of a developed virtual laboratory application including its features, setup of software and laboratory experiments. The purpose was to develop an application to check the effectiveness of virtual environments on students' learning. The study used an experimental design approach in which two groups of students made, one was controlled and other was experimental. The control group performed experiments in a physical laboratory whereas the experimental group used a developed virtual application. There were four control groups and four experimental groups within 184 participants from four secondary schools.

The study collected data through quantitative approaches. The quiz was designed to be similar for both groups and related to experiments performed in physical and virtual laboratories. It was based on 10 multiple choice questions. The statistical methods such as mean, variance, standard deviation and t-test were performed on data of quiz. This compared the students learning from using both laboratories. Effect size was used to measure the magnitude of two groups. The quantitative method also used the SUS questionnaire which was standardized and reliable. This questionnaire used to measure usability and learnability of a virtual laboratory. The experimental group participants solved it in the end after performing laboratory experiments. The usability scores were then calculated using the SUS scoring method.

CHAPTER 4

RESULTS AND DISCUSSION

4.1   Overview

This chapter compared the impact of virtual and physical laboratories on student's motivation towards learning Physics. It also described the student's experience by using both laboratories. The study was quantitative in nature as described in section 3.3. Thus, academic achievement of students was measured through a quiz which was taken from both groups after the experiments were performed.

Therefore, this chapter reported results from both groups in section 4.2. This section assessed the effectiveness of a virtual laboratory including results from boys and girls. The section 4.3 evaluated usability of a developed virtual laboratory application. This section described how much virtual laboratory was usable and also learnable for secondary school students.

4.2   Results

This chapter interprets and reports the data collected during research in order to verify the present study. It also shows results of a student's achievement in learning Physics and the effectiveness of a virtual laboratory over a physical laboratory. There were four schools selected for the study and each one of them had two groups i.e., control and experimental. Both groups had the same experiments, but the difference was that lectures given to experimental group students were in a virtual laboratory that had its own instructional methods. Whereas the

physical laboratory used a direct teaching method, this approach is similar to traditional teaching approaches.

After performing the experiments, a quiz was taken from both groups in order to compare results. These results helped in measuring the effectiveness of learning either through physical or virtual laboratory. The rest of sections described results in detail after analyzing the data.

4.2.1   Quiz Results

A quiz consisted of 10 multiple type questions related to the Physics laboratory experiments, weighing one mark (total 10 marks) for each question. Quiz questions were the same for both groups and all participants were allocated some time which was 20 minutes to complete quiz. Table 4.1 shows the quiz scores of participants from both laboratories (virtual and physical). According to Table 4.1, scores were classified into three different categories on the basis of score range. The quiz scores between a range of 8 to 10, were listed into the category of excellent (above average). Similarly, scores between 5 to 7 were considered to be in the fair category (average) and scores between 0-4 were considered into the poor category (below average).

Table 4.1: Participants quiz scores after using the virtual and physical laboratories

Score Range	School 1		School 2		School 3		School 4	
	EG	CG	EG	CG	EG	CG	EG	CG
8-10 (Excellent)	14	6	11	7	10	7	9	7
5-7 (Fair)	8	15	10	11	9	9	9	7
0-4 (Poor)	5	6	2	5	3	6	2	6

Results showed that most of experimental groups (EG) scores in all four schools were in the category of excellent (ranging between 8 to 10) when compared to control groups. The highest scores in an excellent category by experimental group of school 1 was 14 (51%). This count depicts that participants of this category somehow achieved desired knowledge of Physics experiments. Fair category also contained the majority of experimental groups scores, maximum to 9 (45%). The category of poor consisted of some low range scores and the ratio was lower as compared to control groups. Maximum 18% of participants scored below average i.e. scores ranged between 0 to 4.

On the other hand, when a quiz scores compared to control groups (CG) it can be seen that numbers were less in the excellent category. The highest number of scores gained in this category was just 7 (35%) by school 4. Among the control group, participants' scores ranged between 5 to 7, which falls into the fair category. The maximum scores in this category were 15 (55%) achieved by school 1 participants. The results also showed that a majority of scores also ranged between the poor category by participants of control group which was maximum to 30%.

Thus, results of both groups in Table 4.1 showed that student learning achievement towards Physics experiments was increased when they used a virtual laboratory application. Participants of a virtual laboratory scored highest marks maximum to 51% which was more than marks obtained by a physical laboratory participant. Most of the physical laboratory participants scored zero or near to zero marks when compared to participants of virtual laboratory. The poor ratio for a virtual laboratory was comparatively low. Figure 4.1 represents the number of scored marks between score ranges.
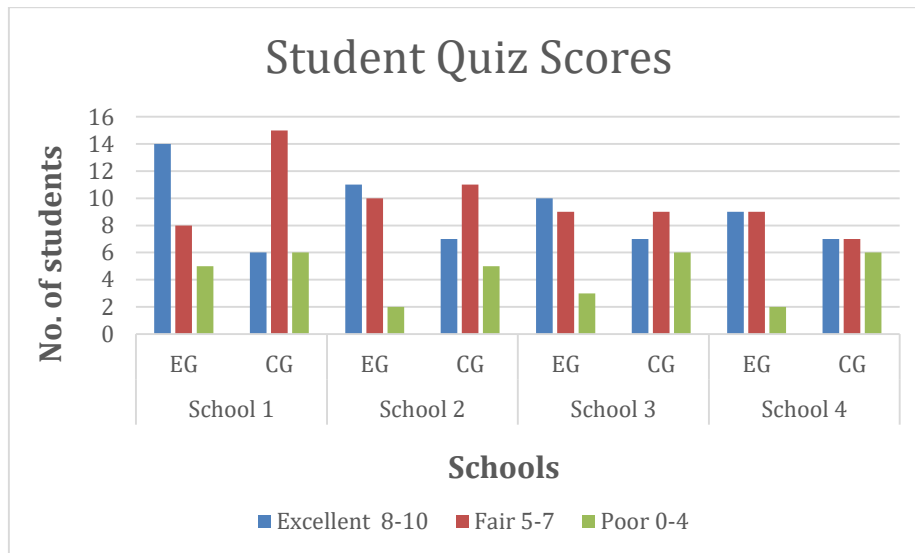
Figure 4.1: Participants Quiz Score Ranges

4.2.2   Statistical Treatment of Data

In this section, some statistical methods were applied on raw data collected from the user study. The sole purpose was to transform meaningless raw data to meaningful output. These techniques also helped in describing the nature of data and explored the relation of data to the population under study. As discussed in section 3.7, the applied statistical techniques in this study were descriptive and inferential.

The descriptive statistical analysis in this study tended to give a summary of collected raw data in the form of a table or chart. But it was not attempted to give any conclusion about the sample which was taken from under-studying population. In Table 4.2, which showed the descriptive analysis included a mean, standard deviation and variance for two groups.

Table 4.2: Descriptive Statistical Analysis

Groups	N	Mean ($\bar{x}$)	Standard Deviation (σ)	Variance (S^2)
Experimental	92	7.16	2.14	4.59
Control	92	5.86	2.45	6.02

The mean represented the central tendency in the given data set and according to Table 4.2 the means for both groups were M=7.16 and M=5.86 respectively. The standard deviation expressed as the theoretical calculation that about 68% of measurements lie either side of the mean within one standard deviation. Thus, the best mean score for an experimental group was 7.16 ± 2.14 which means 7.16-2.14=5.02 and 7.16+2.14=9.3. So, the total number of scores between 5.02 and 9.3 were 68 (74%) from 92. Similarly, the mean scores for the control group were 5.86 ± 2.45, 5.86-2.45= 3.41 and 5.86+2.45= 8.31. The total number of scores between 3.41 and 8.31 were 71 (77%). Both percentages fell within one standard deviation of the mean on either side. On the other hand, the calculated variances for experimental and control groups represented the degree of spread-out data about their mean. The control group variance was small $S^2 = 4.59$ as compared to the experimental group $S^2 = 6.02$, this means that data points were closed to a mean. Whereas, the data points for experimental groups tend to be scattered to some instant.

The inferential statistical technique was also used in this study to compare the treatment groups measurements from a sample. For this purpose, the two-sample z-test was used as a statistical test which was applied to find differences among quiz mean scores of two groups. In this test, the statistical significance was determined with the confidence interval of 95%, so the significance level (alpha value) was considered as 5% (0.05). The Table 4.3 shows a complete z-test results applied on two groups i.e., experimental and control.

Table 4.3: Inferential Statistical Analysis

Z-test Scores	Experimental Group	Control Group
N	92	92
Mean	7.163043	5.869565
Z Score	3.80	
Z critical two tail	1.959964	
P(Z<=z) two-tail	0.000141	

The results of a z-test in Table 4.3 showed that mean value of an experimental group M=7.16 higher than the mean value of a control group M=5.87. The Z score for 184 total participants was Z (184) = 3.80. Additionally, it was found a significant difference between the

mean scores of experimental and control groups. The p value (p=0.000) was smaller than the significance level (p<0.05), indicating that results were statistically significant.

According to Table 4.3, z-test results were in the favor of experimental group which used a virtual laboratory for learning Physics experiments. The results were statistically significant which shown in Figure 4.2. This tended to explain that provision of a virtual laboratory application used as a substitute to a physical laboratory had a positive effect on the learning performance of the experimental group.
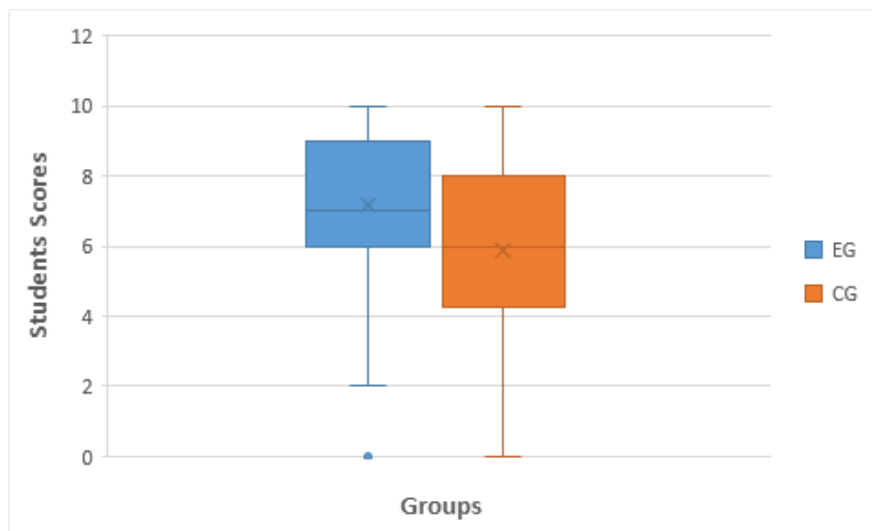
Figure 4.2: Boxplot of Participants Scores

4.2.3   Comparison of Means for Schools

The average quiz mean scores of both groups were also calculated for four schools which is shown in Table 4.4. Almost all participants of the experimental group scored better as compared to the control group. This shows that performance of these participants was improved when using a virtual laboratory. The mean quiz scores were summarized in the below table.

Table 4.4: Quiz Mean Scores

Groups	School 1	School 2	School 3	School 4
Experimental Group	7.4	7.3	6.9	7
Control Group	5.6	6.2	5.9	5.8

In this study, the performance of experimental groups at different schools was also evaluated. It was observed that school 1 performed better than other three schools, with the mean score of M=7.4. This mean score was found higher among other experimental groups which is shown in Figure 4.3. According to Table 4.4, it can be seen that school 3 had the lowest mean for experimental group.
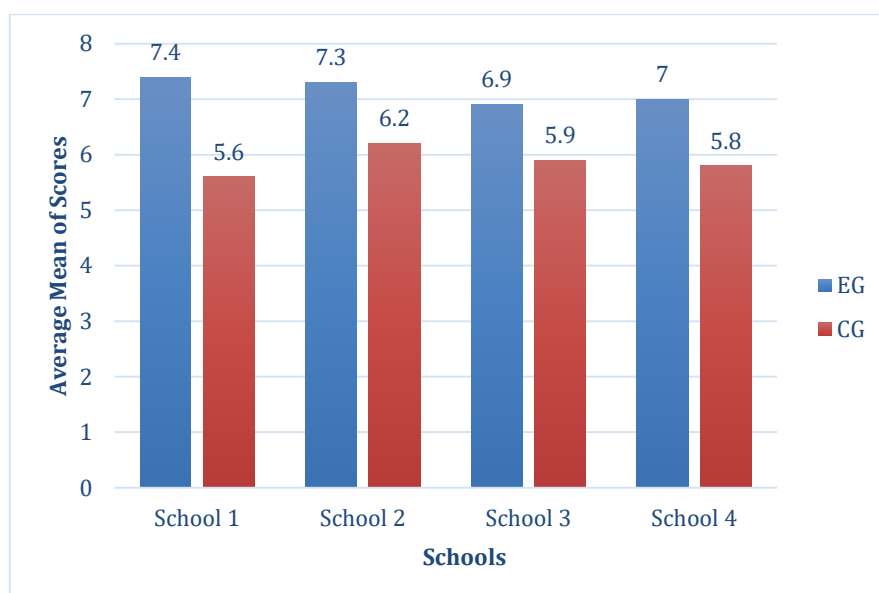
Figure 4.3: Comparison of mean quiz scores for EG and CG

4.2.4   Comparison by Gender

The scores of quizzes for both groups were also evaluated on a basis of gender. The purpose was to check effectiveness between boys and girls when using a virtual laboratory. The total number of boys and girls were 99 and 85 respectively, which were distributed in

experimental and control groups. This distribution of participants was represented in Table 4.5 with mean and standard deviation.

Table 4.5: Comparison based on gender

Groups	Gender	School	N	Mean	Standard Deviation
EG	Boys	School 1	9	7.9	1.8
		School 2	8	7	2.2
		School 3	15	6.8	2.33
		School 4	13	7.4	1.97
	Girls	School 1	18	7.1	2.35
		School 2	15	7.4	1.74
		School 3	7	7	2.2
		School 4	7	6.4	2.2
CG	Boys	School 1	13	4.9	2.02
		School 2	12	6.6	2.6
		School 3	11	6.8	2.8
		School 4	12	5.9	2.3
	Girls	School 1	14	6.1	1.99
		School 2	11	5.8	1.97
		School 3	11	5.1	2.9
		School 4	8	5.6	2.8

The data in Table 4.5, reported that there was no such difference found between boys and girls in the experimental group. This meant that both gender groups learned and performed experiments well using a virtual laboratory. However, according to results, boys performed better than girls in school 1 with M=7.9. On the other hand, the mean scores of boys and girls were different from school to school in the control group. The mean score of boys in school 3 was highest M=6.8 from the rest of mean scores of control groups. The differences between both groups can be seen from Figure 4.4 and Figure 4.5 with mean scores and use of standard error mean.
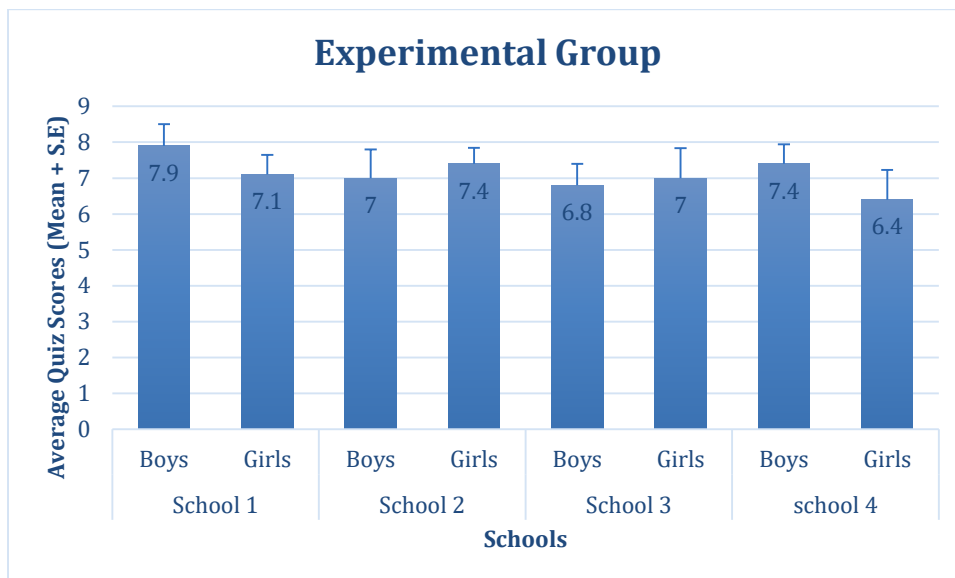
Figure 4.4: Comparison of boys and girls in experimental group
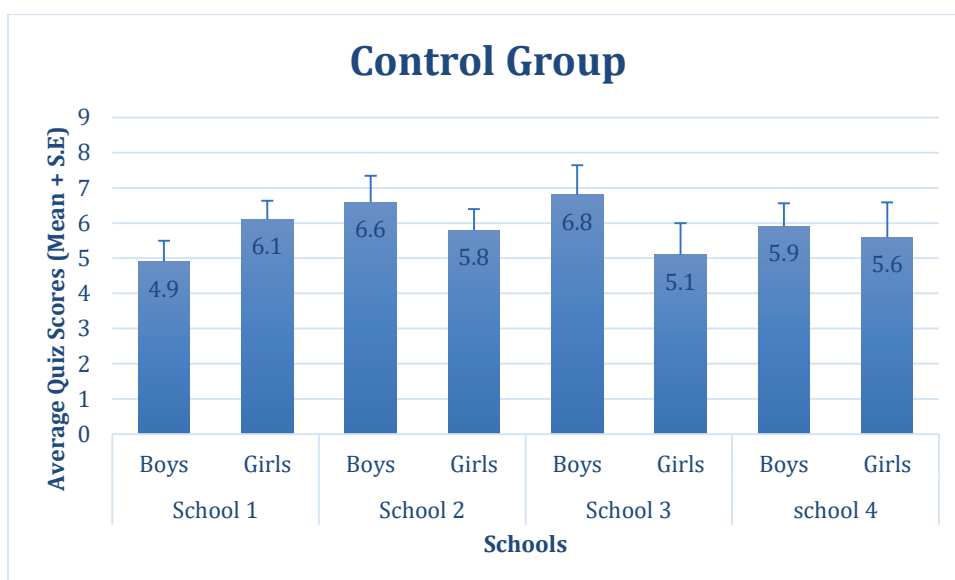
Figure 4.5: Comparison of boys and girls in control group

In order to confirm that there was a significant difference between boys and girls in the experimental groups, the z-test was applied to a quiz data. According to Table 4.6, boys in the experimental group were 45 and girls were 47 with mean values of M=7.24 and M=7.2 respectively. The value of p was also greater than alpha value 0.05 (p>0.05). This means that there was no significant difference found when comparing boys and girls in the experimental group. Each participant performed well according to their understanding. Furthermore, results showed that learning through a virtual laboratory was similar for both gender groups.

Table 4.6: z-test of boys and girls for virtual laboratory

Groups	N	Mean	Variance	Z Value	P Value
Boys	45	7.24	4.69	0.12	0.905
Girls	47	7.2	4.55		

4.2.5   Comparison by Time Difference

The study also compared results on a basis of time constraints between the experimental and control groups. Time was also the main factor that caused the use of a virtual laboratory. During the research, performance of each participant was measured on the basis of time. This time was the completion of each four Physics experiments. At the start of a research, participants of both groups were given a 5 min introduction about the purpose of this study. Table 4.7 shows the allocated time for each task for participants of two groups.

Table 4.7: Time allocation for each task

Tasks	Virtual Laboratory	Physical Laboratory
Training	15 min	N/A
Exploration	15 min	15 min
Experiments performed	40 min	40 min

The virtual laboratory participants began with 15 mins training through a developed application. This training included the use of a 3D environment and how things worked in a laboratory. After the training stage, participants explored the virtual laboratory which was an accurate model of real Physics laboratories. The allocated time for exploration in a virtual laboratory was 15 mins. When participants understood the working of virtual objects, they started performing experiments using an application. The estimated time for performing experiments was 40 mins, although this time may fluctuate on the basis of completion time of each experiment by participants.

The training phase for physical laboratory participants was not applicable to them because they already knew the environment of a real laboratory. Somehow, they also explored the physical laboratory equipment for 15 mins like virtual laboratory participants. They got the knowledge about apparatuses for four Physics experiments which were explained in section 3.2.3. Participants performed same experiments like the virtual laboratory but used real tools instead of virtual objects. The completion time for these experiments was 40 mins, but time may differ from participant to participant depending on the experiments performed.

The time difference among both groups was evaluated on the basis of time taken to perform experiments. The experimental and control groups started experiments at the same time and completion time of experiments were also recorded for each participant. The summary of average time for both groups recorded in a Table 4.8.

Table 4.8: Completion time for experiments

	School 1		School 2		School 3		School 4	
	EG	**CG**	**EG**	**CG**	**EG**	**CG**	**EG**	**CG**
Maximum Time (min)	36	50	35	55	40	57	40	60
Minimum Time (min)	16	30	15	35	18	26	19	35

As seen in Table 4.8, the overall maximum time range for experimental groups from 35 minutes to 40 minutes. Whereas, the minimum time ranges from 15 minutes to 19 minutes. Similarly, the maximum time range for control groups of four schools was from 50 minutes to 60 minutes and minimum 26 to 35 minutes. According to the recorded time values which shows that a virtual laboratory is the preferable application because of their easy to use 3D environment. The calculated mean time of experiments for four schools are given in Table 4.9.

Table 4.9: Calculated mean time

Schools /Groups	School 1		School 2		School 3		School 4	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
EG	25.2	5.8	26.5	4.6	28.6	5.6	29.1	5.5
CG	40.7	4.9	44.5	5.3	43.5	7.6	46.4	7.4

The results showed that mean time of experimental group participants had the lowest values as compared to control group participants. These mean values proved that performance of participants using virtual laboratory were way better than participants of physical laboratory. The results also depicted that mean time of school 1 participants using a virtual laboratory was the lowest among experimental groups of other three schools with M=25.2 and SD=5.8. The maximum values in this group were M=29.1 and SD=5.5 for school 4. On the other hand, the highest mean time value for control group participants was M=46.4 and SD=7.4, this value determined that control group participants took longer time to perform experiments. Whereas, the lowest value in this group was M=40.7 and SD=4.9 for school 1 which was also larger than the lowest mean time of experimental groups. Figure 4.6 represented the mean time values for both groups with standard error mean.
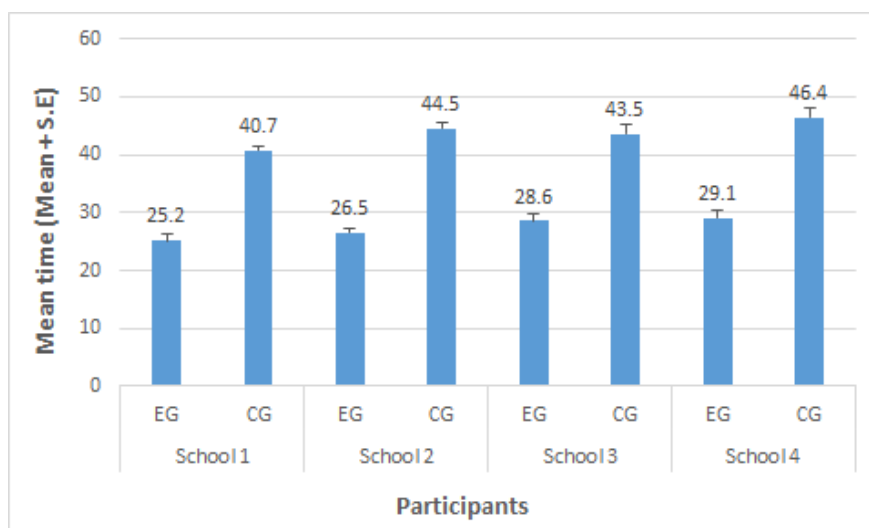
Figure 4.6: Mean time for EG and CG groups

In order to find the statistical difference among time taken by two groups, a z-test was applied on the recorded time which shown in Table 4.10. The two-sample means analyzed that there was a significant difference of time between two groups i.e. z (184) = -18.1 with p=0.00 where p is less than alpha value (p<0.05). This value indicates that a virtual laboratory can be a valuable tool for students to perform better in Physics experiments.

Table 4.10: z-test for experiments completion time

Groups	N	Mean	Variance	Z Value	P Value
EG	92	27.2	32.4	-18.1	0.00
CG	92	43.5	43		

The Figure 4.7 shows an average time taken by participants of two groups for four Physics laboratory experiments. It can be clearly seen in the line graph that a physical laboratory group took more time to complete experiments while a virtual laboratory group took less time. It was also observed that experiments performed in physical laboratories were time consuming and most of the time was wasted on setting up apparatuses. This was one of reasons why the control group took more time than experimental group.
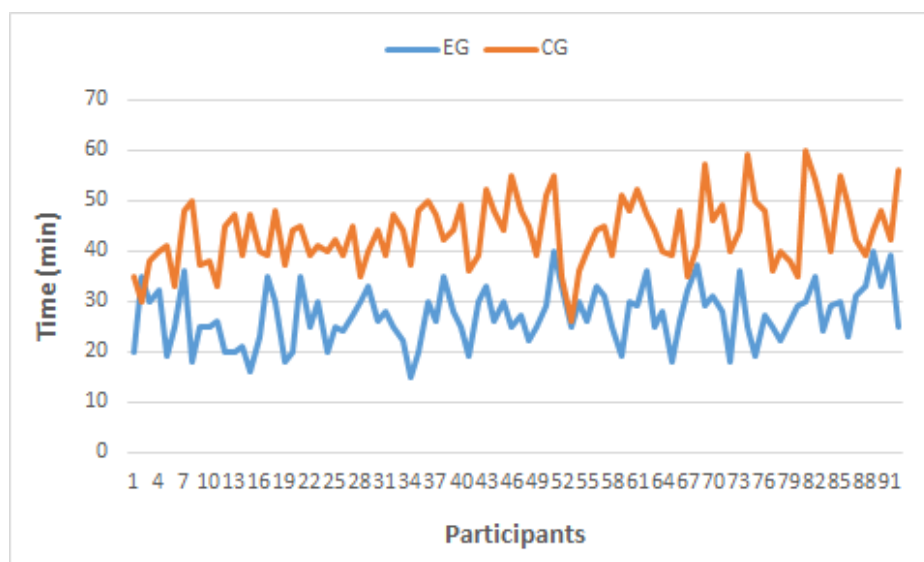
Figure 4.7: Time to perform experiments by each participant of two groups

The time taken to complete experiments by boys and girls for two groups can be seen in Table 4.11. There were 45 boys and 47 girls in the experimental group. The maximum time for completing experiments by gender varied according to participants. The summary shows that average time for boys (27.2 min) and girls (27 min) of the experimental group was almost the same and did not find any significant difference. This confirmed that both genders used a virtual laboratory with interest without any struggle. Furthermore, the average time for control group participants of boys and girls was found to be little significant with 42.3 and 44.8 minutes.

Table 4.11: Time variation based on gender

Groups	Gender	N	Minimum Time (min)	Average/Mean Time (min)	Maximum Time (min)
EG	Boy	45	18	27.2	40
	Girl	47	15	27	40
CG	Boy	47	30	42.3	54
	Girl	45	26	44.8	60

4.2.6   Effect Size

The result of a z-test was found significantly different for the quiz of experimental and control groups but this value was not sufficient for decision making. In order to quantify the meaningful results, the effect size was also calculated in this study. This helped in calculating the magnitude differences between two groups and between boys and girls [185]. This study used Cohen's d [187] method, which is one of the types of effect size. Cohen's d calculated on a basis of difference between the two mean and results divided by pooled standard deviation. Cohen's guides are categorized into specific ranges which are given below:

1.   Trivial (< 0.1)
2.   Small (0.1 - 0.3)
3.   Moderate (0.3 - 0.5)
4.   Large difference (> 0.5)

Table 4.12 shows the mean value M=7.16 for experimental group and mean value M=5.87 for control group. The calculated effect size result is 0.5 which means there is a medium or moderate difference between groups. According to Cohen [187], this difference still counts as large enough to be seen by naked eye.

Table 4.12: Effect Size for EG and CG

EG	CG		Effect Size
Mean	**Mean**	**SD**	
7.16	5.87	2.44	0.5

From section 4.2.4, the result found that there was no significant difference between boys and girls. This can also be confirmed by evaluating through its effect size. Table 4.13 shows the mean value M=7.24 for boys and mean M=7.2 value for girls. The calculated effect size result is 0.01 which means that difference between two genders is less than the trivial category (<0.1), so the difference is negligible in this case.

Table 4.13: Effect Size of boys and girls for experimental group

Boys	Girls		Effect Size
Mean	**Mean**	**SD**	
7.24	7.2	2.13	0.01

4.3   System Usability Scale Analysis

The System Usability Scale (SUS) questionnaire was circulated among participants of experimental groups after their completion of a quiz. This questionnaire was filled by 92 participants who used the virtual laboratory application. Among participants, boys were 45 (48%) and girls were 47 (51%). The main focus for conducting a SUS survey was to evaluate the usability of an application and measure satisfaction level of participants. The SUS

questionnaire also assessed student's learning after performing experiments through the virtual laboratory.

The SUS questionnaire consisted of 10 items and each respondent on the SUS questionnaire was valued between 1 and 5 points (strongly disagree to strongly agree). The odd numbered items responses were minus 1 from each score and even numbered items were minus 5 from each score. The odd and even items scores were then added and the result was multiplied by 2.5. The calculated SUS score for each participant ranged from 0 to 100 and these scores scaled on percentiles rather than percentages. The interpretation of SUS scores based on ranges which are presented in Table 4.14 and a score of 68 is considered to be average with 50th percentile [188].

Table 4.14: Interpretation of SUS Scores

SUS Rating	SUS Score
Excellent	> 80.3
Good	68 – 80.3
Okay	68
Poor	51 – 67
Awful	< 51

According to Table 4.14, the rating 'Okay' is the average SUS rating, it means that all systems are this level of usability. All other scores lie above or below average SUS rating. The association between the SUS percentile and scores can be seen in Figure 4.8.
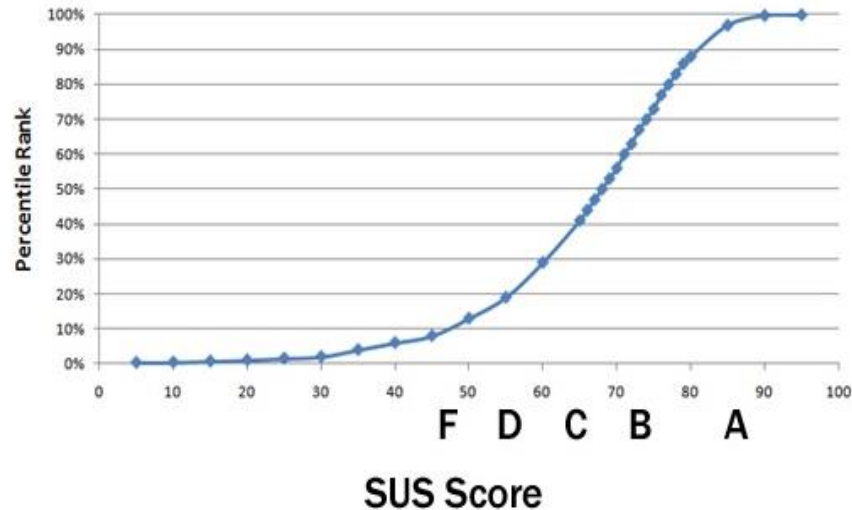
Figure 4.8: Relationship between SUS percentiles, scores & grading or rating [189]

4.3.1 Reliability Analysis

The reliability of a SUS questionnaire was evaluated through Cronbach alpha or Coefficient alpha. Cronbach alpha is a commonly approved test for measuring the reliability coefficient of a questionnaire. The purpose of this test is to determine internal consistency of a questionnaire before it is used in research. It is expressed on scales from 0 to 1 and if the measured value of Cronbach alpha is close to 1, it is considered as good internal consistency among items [190]. In this study, Cronbach alpha was calculated and the value was 0.76. This value was between 0 to 1 and also closer to 1, so it was acceptable for the reliability test.

4.3.2 Descriptive Analysis

The descriptive statistics information for SUS scores obtained from the present study which is shown in Table 4.15. According to results, the SUS score achieved was 73.5 which is above average score (68). This score is considered to be a good [189] for the usability of a developed application.

Table 4.15: Summary of SUS Scores

SUS Result	SUS Values
N	92
Minimum Score	32.5
Maximum Score	97.5
Average SUS Score	73.5
Standard Deviation	13.7

The responses of participants for SUS are represented in Figure 4.9, which shows the visual overview for each item response distribution. Each item was calculated in percentages in order to check participants satisfaction level for the developed application. These responses are discussed in the following bulleted items.

Item 1: From Figure 4.9, it can be seen that 82 % participants would like to perform experiments on a virtual laboratory application during their studies. Results also show that 9% of participants were neutral regarding this.

Item 2: It was reported that 66% of participants did enjoy the application and didn't find any complexity. While 17% of them didn't like it and the remaining 15% were neutral.

Item 3: The high proportion of participants (85%) agreed that the application was easy to use, 9% participants came with neutral results. There was no issue encountered while using the application.

Item 4: The virtual laboratory application was designed in such a way that all instructions for experiments were displayed on the screen for participants. So, they didn't need help from the technical person for performing experiments. About 50% of participants responded that they didn't need a technical person. Whereas, 35% participants needed technical assistance while 13% of them were neutral in this case.

Item 5: The main element of a virtual laboratory was Physics experiments which consisted of virtual objects, text and images. Each item in experiments was arranged all together according to the topic. Almost 79% participants found experiment's interfaces were well integrated and they easily understood the experiment flow.
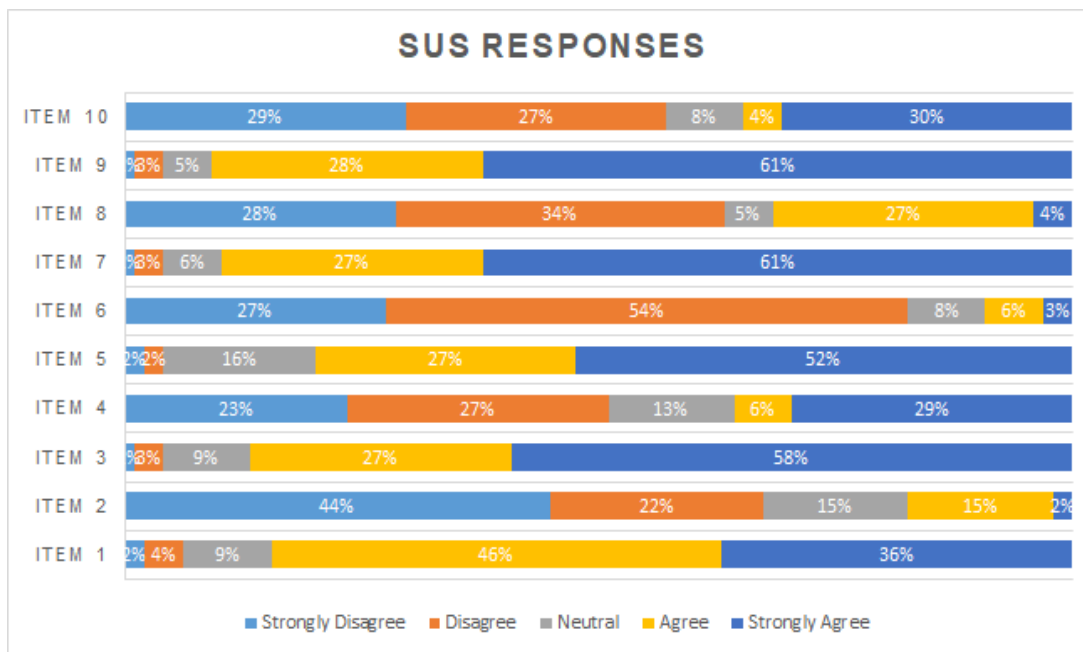
Figure 4.9: Participants responses to SUS items

Item 6: It was observed that the design of a virtual laboratory's user interface was consistent, participants were easily navigated to other screens without any hesitation. As shown in Figure 4.9, 81% participants disagreed with the inconsistency in an application. Only 9% of participants agreed that the application was not coordinated and 8% were neutral.

Item 7: 88% of participants agreed that they would like to use this type of virtual laboratory in learning their practical skills. However, there were few participants (4%) who disagreed with this application and the rest of participants (6%) were neutral.

Item 8: All elements and components of the application were well integrated and coordinated so that each participant can easily use it, but 31% participants found it difficult to use. While 62% of them were happy with procedures and 5% were found neutral.

Item 9: The response of this item was 89% and participants were very confident in using virtual laboratory application. Only 5% of them were found to be unconfident with 4% natural among 92 participants.

Item 10: As discussed above, the application was easy to use for participants. All the information about experiments were displayed on the screen so there was no need to learn much about it. In this study, 56% of participants said that they didn't require any learning for using the application. However, 8% of them had no opinion about this item. Furthermore, 34% of participants want to learn about the virtual laboratory before using it.

The interpretation of the SUS was based on scores which were then converted into the percentile rating. Table 4.16 shows the descriptive statistical results for SUS scores which are distributed according to SUS rating scale.

Table 4.16: Descriptive Analysis of SUS results

SUS Rating	Frequency (F)	Mean Score (M)	Standard Deviation (SD)
Excellent	31	87.74	4.11
Good	28	75.36	3.18
Okay	0	0	0
Poor	26	62.4	5.21
Awful	7	45	7.19

According to Table 4.16, the score ranges from above and below average SUS score (68). This study found a maximum number of frequencies F=31 in Excellent SUS rating. This depicts that most of SUS scores were more than 80.3 (see Table 4.14) with mean score M=87.74 and standard deviation SD=4.11. The rating scale 'Good' counts 28 scores between the range 68 – 80.3. The count is second largest among SUS ratings with mean score M=75.36 and SD=3.18. This rating is also acceptable because it's above average. In this study, there were no

scores found in the 'Okay' rating nor equals to 68 score. The below average score falls in 'Poor' rating with count of F=26. Scores were calculated between the range of 51 and 67 with M=62.4 and SD=5.21. This rating is only acceptable marginally. The 'Awful' rating consisted of low frequency F=7 with low level of SUS scores which were less than 51. This gain of low-level scores were because of misunderstanding of questions or participants didn't pay attention while filling up the questionnaire. The SUS means scores with standard error mean vs SUS rating shown in Figure 4.10.
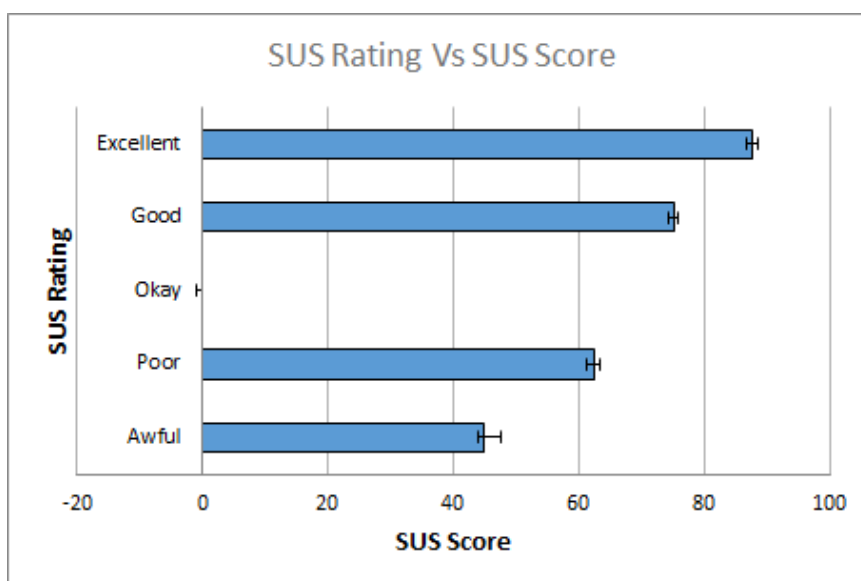
Figure 4.10: Mean SUS score with standard error of the mean

4.3.3 Positive-Negative Items

The 10 SUS items contain mixed questions, i.e. there are five positive questions which are also known as odd numbered items (1,3,5,7,9) and other five are negative tone questions with even numbered items (2,4,6,8,10) [191]. Both types scaled from strongly disagree to strongly agree (1 to 5). The average of both even and odd numbered items are described in Table 4.17 with calculated standard deviation.

Table 4.17: Descriptive Analysis of items

Items	N	M	SD
Positive	92	21.62	0.15
Negative	92	2.44	0.4

In Figure 4.11, the box plot shows a positive and negative SUS items. The graph divides items with green (positive) and red (negative). Indeed, positive items related to the satisfaction or likeness towards a virtual laboratory application. Thus, it had higher scores which showed on the agreed side of a graph. Whereas negative items show dislike, dissatisfaction or discomfort in using the application. The negative items scored lower and plotted on the disagreement side of a graph. This semi assessment shows that participants were willing to use the virtual laboratory in their studies.
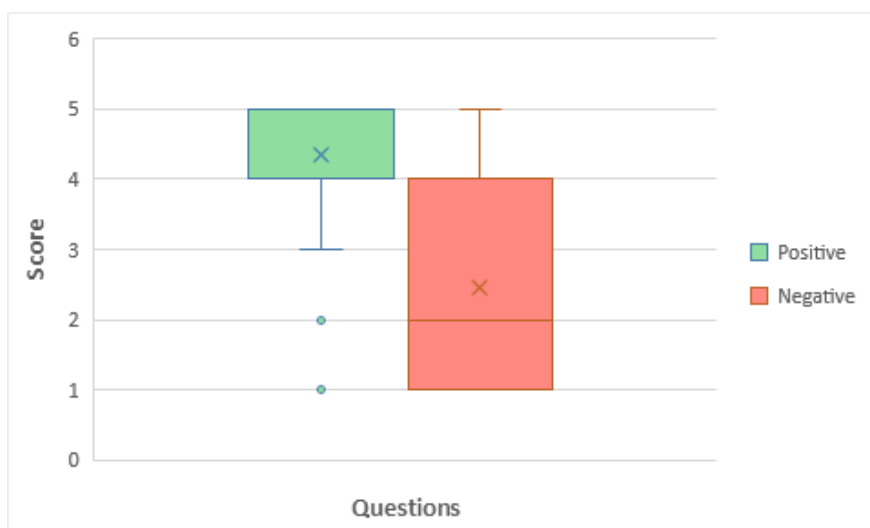
Figure 4.11: Box Plot for positive-negative SUS items

4.3.4   Usability and Learnability Analysis

The SUS is designed as unidimensional meaning it is perceived to measure only usability. Studies have found that it is multidimensional which has two factors i.e. usability and learnability [192]. The study also reviewed usability and learnability factors of a virtual laboratory which was based on the SUS questionnaire. Items 1, 2, 3, 5, 6, 7, 8 and 9 are included

in a usability factor. From Table 4.18, the mean value of usability shows 28.25 with SD=4.3. The results concluded that participants agreed and gave positive responses for the use of a virtual laboratory.

Table 4.18: Descriptive Analysis of usability-learnability factors

Factors	N	M	SD
Usability	92	28.25	4.3
Learnability	92	5.7	3.0

Similarly, the learnability factor contained items 4 and 10 and results showed that the learnability factor mean value is 5.7 and SD=3.0. The lower mean for learnability is suggested better because items included in this are negative [193]. Participants did not agree that the developed application was complex. Furthermore, they also disagreed with the statement stating that participants need to learn and understand things before using a virtual laboratory. The usability and learnability factors use both positive and negative items so participants also agreed or disagreed with items. Thus, Figure 4.12 showed results in percentages according to the agreement or disagreement of items. It can be seen that 82% of participants agreed that they learned from the developed application while 74% participants thought that the virtual laboratory application was easy to use. According to [194], in most of the cases, learnability score is greater than a usability score. Thus, results show a greater learnability score in percentages when compared to usability and general SUS score.
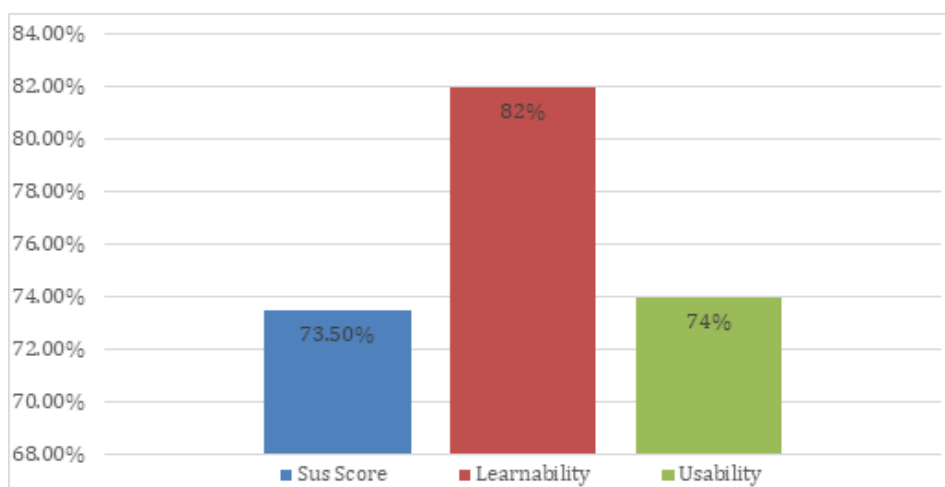
Figure 4.12: Usability and Learnability analysis compared to SUS Score

4.4 Discussion

In a present study, results gathered from virtual and physical laboratories. The main purpose for this study was to investigate the effectiveness of a virtual laboratory in comparison with physical laboratories. The results showed that learning of experimental group students was better than control group students. This findings were similar to the findings of study [103] in which the research was conducted with 58 participants of higher school and results showed that students in the experimental group achieved desired science skills. Furthermore, the present research also found statistically significant result with a value of p=0.000141 (p<0.05). This statistically significant result was similar to the results found in [107] which was conducted on the concepts of chemistry.

The study also revealed during observation that experimental group participant's interest towards learning was comparatively higher than control group. This observation was also seen in study [69] in which students who used VR application were more interested in learning as compared to students using traditional approach. In the present research, students were eager to try out this new technology for learning. This excitement turned out to be more engaging for students to use a virtual laboratory. They were attracted to features of the virtual laboratory application. They liked interfaces, colors and conceptual designs [21] of Physics experiments. They were also easily dragged & dropped virtual objects and navigated through different screens. It was also discovered that they didn't face any difficulty reading any text on the application and understood every step for performing experiments. Thus, the students of experimental group were actually enjoyed performing experiments using virtual laboratory. The results found similar to the study [34] which conducted using concepts of Physics with students of primary level and they liked performing experiments.

The research also observed that students of the control group did not pay attention when teachers taught through traditional teaching mode. This absence was affected on their quiz scores which can be seen in Table 4.1. The average score in a poor category of control group was 25% and when this was compared to a poor category of experimental group (13%) then this score was even greater. On the other hand, it was observed that the experimental group's interest towards virtual laboratory simply increased engagement level with the application. The average score in an excellent category of experimental group was 48%. This observation is

comparable to [195], which reported that emotional stimuli are valuable in order to achieve learning effectiveness and motivation through a virtual laboratory.

It was also observed that insufficient computer skill was also one of the factors which caused low quiz scores at School 3 with the mean score of 6.9. Due to this, students might not be able to perform experiments efficiently in virtual laboratory application. In contrast, School 1 laboratory infrastructure was better than School 3. Thus, students performed well with the mean score of 7.4.

The study involves mixed gender i.e., boys and girls in both experimental and control groups. Results showed that there was no significant difference found between genders of experimental group. From Table 4.6, the mean score for boys and girls were 7.24 and 7.2 respectively with p value of 0.905 whereas $p > 0.05$. The results also did not find any significant difference between genders of for control group ($p = 0.9$ whereas $p > 0.05$). This study results are different than [196] which also discusses gender comparison and it found that male performed better than females when using a virtual laboratory.

The study also observed time constraint for both virtual laboratory and physical laboratory. Each task was allotted time and then observed in both groups upon task completion. It was revealed after applying a z-test that results were significant $p=0.00$ ($p<0.05$). It means participants of a virtual laboratory performed experiments with less time as compared to a physical laboratory. The findings are different than [197], the researcher observed time for both participants and concluded that there was no significant result found.

Regarding the limitation of this study, it covered only 184 students from four schools it can be conducted with multiple schools in different regions with number of students, this may help in better generalization of results. Secondly, the lack of student interest in a control group may be improved by making teaching sessions more engaging and interesting. Thirdly, the limited resources within schools may also affect student's performance.

It was also observed that the students who had already learned about virtual reality didn't give a response after the experiment was performed even though they were instructed about the

technology. This was because they didn't understand the essence of the study we were trying to explain. Therefore, it is possible that the results may differ from the core values of the study.

4.5   Summary

This chapter discusses results of data collected. The main focus was to find the effectiveness of learning through a virtual laboratory for secondary school students. It was found through quiz results that participants of a virtual laboratory performed better than a physical laboratory. This was verified after applying the z-test on quiz data and achieved statistically significant results. It was noticed that the performance of school 1 was good among other schools because this school was located in an urban area which was equipped with facilities like computers. This study also compared results between boys and girls of an experimental group and found no significant differences. Both genders performed experiments and understood the Physics concepts. The virtual laboratory application was also effective in terms of time and findings showed a significant difference between both groups. Through a usability questionnaire (SUS), it was revealed that virtual laboratory application is a valuable tool for learning Physics concepts and easy to use for students who want to adopt this new technology in their learning process.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1   Overview

This chapter concludes work which was presented in the thesis (section 5.2), discusses some contributions of the study (section 5.3) and provides suggestions for future work in this research area (section 5.4).

5.2   Conclusion

This research investigated secondary school students learning in Physics laboratory concepts. The investigation was based on two laboratory types, one in a physical or traditional laboratory and another one was a virtual laboratory. The physical laboratory includes a hands-on approach to different equipment, models, learning materials etc. using a face to face environment. Whereas, in a virtual laboratory student learn concepts using the computer application in student's own time.

This study tends to evaluate the effectiveness of learning through a virtual laboratory. To do this, the first research question sought to find key parameters of learning for secondary school students.

RQ1: What are the key learning parameters for secondary school students?

The research found several different categories of key learning parameters from literature which affects the student's learning for secondary school [117]. These categories include affection between the student and teacher in a learning process. Teachers build a comfortable environment where students can increase their interest in studying and learning. The second category is cognition which involves gaining and learning new concepts from learning materials. Behavior is the third category which helps students to be motivated in a classroom environment. Positive behavior is important in learning because without this student loses their interest in the subject. The fourth category is learning skills which involve different life skills like problem solving, cognitive abilities and creative thinking. The fifth category is correlation which is the relationship between a student's achievement and learning approaches.

The research was also focused on the user-friendly design of virtual reality applications. The second research question sought to identify design guidelines of virtual reality applications from the literature. These guidelines also determine whether they are still applicable within the area of education.

RQ2: What are the design guidelines that exist for VR applications in education?

The literature also found some design guidelines [144][145][146] for virtual reality which take these into account when designing applications in virtual environments. These guidelines include: reduce degree of freedom like use 2D controls which are easier to handle and users can easily interact with them. Sickness should be reduced through minimizing brightness, acceleration and images. The 3D environment needs to use depth cues which includes occlusion, shadows, relative size, atmospheric perspective, linear perspective, motion parallax and texture gradients. Create a UI design in such a way that it interacts with users so they can explore the features within an application. The user guide helps users to move and explore within a 3D environment. Make controls easy for users to learn because users can remember a limited amount of information. Use of real-world objects into the virtual world helps users to quickly understand a virtual environment. The items in an application should be spaced and scaled properly. This can be done through using Gestalt principles such as proximity, similarity and hierarchy. The application should always give feedback as a message

to users about whether a task was performed successfully or not. The use of audio in the background also plays an important role for users to interact with the 3D environment.

The third research question tried to find how student's learning was affected when using a developed virtual laboratory application associated with learning parameters and design guidelines.

RQ3: How does the Virtual laboratory application affect the student's learning?

The study was conducted on students of secondary schools who were studying one of the STEM subjects, which was Physics. Two laboratories were used i.e. traditional and a virtual laboratory, the main focus was to compare effectiveness of learning Physics practical skills using both laboratories. To do this, a virtual laboratory application was developed based on the Physics laboratory experiments associated with learning parameters and design guidelines. Through findings, it was concluded that the virtual laboratory can replace physical laboratory because it enhances student performance and learning achievement. The results also support previous studies which reported that learning in a virtual laboratory is good as compared to physical laboratory. The present study implicated that a virtual laboratory has potential to help students with their conceptual understanding towards learning Physics laboratory experiments. It also concluded that learning in a virtual laboratory does not hinders any gender. The findings revealed no significant difference between boys and girls in secondary school performance. The study also concluded that time is the main factor in completing tasks in both laboratories. The task completion time by students of a virtual laboratory is shown better than physical laboratory.

The evaluation of usability when using SUS which provided meaningful and reliable feedback. It was used to analyze student satisfaction after using the virtual laboratory. The general SUS score indicated that students were interested and satisfied with the usability of an application. It was observed that interest of students towards using a virtual laboratory also increased and they found it very usable. Lastly, the learnability factor shows that an application is easy to use for learning.

5.3 Contribution

The emerging technology of virtual laboratories enhances student learning in STEM education, especially in the laboratory. Thus, this developed application supports secondary school students where they show less interest towards the Physics experiments and fail to understand concepts. Most schools lack laboratory facilities, so this application has potential to save cost of equipment or infrastructure. It also saves long working hours for performing experiments. The virtual laboratory application enables students to perform dangerous and difficult experiments which are not possible to perform in physical laboratories.

5.4 Future Work

The use of a virtual laboratory is a relatively new technology in science laboratory education. However, the study concluded that a virtual laboratory is best suited over a physical laboratory. There is a limitation to not transform all Physics experiments into a virtual laboratory. This research recommended to include all Physics course experiments for secondary school education

Furthermore, this study is related to the usability of a virtual laboratory application, different studies can be conducted in the future by taking other metrics (e.g. motivation, performance, scalability, capability etc.) in order to extend this research. Moreover, the developed application is not accessible during the current COVID-19 pandemic which affects educational learning worldwide. The study suggested future enhancements to transform this desktop based virtual laboratory into an online virtual laboratory. This will help self-isolated students learn during COVID-19. Moreover, other STEM subject's laboratory experiments should also be integrated into the virtual laboratory. This will act as a learning tool where students can contribute in the area of STEM education.

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APPENDIX A

PHYSICS EXPERIMENTS QUIZ

Personal Information

Laboratory Type: ☐ Physical   ☐ Virtual

Full Name: _____   **Age:** _____

Gender: ☐ Female   ☐ Male   **Class:** _____

_____
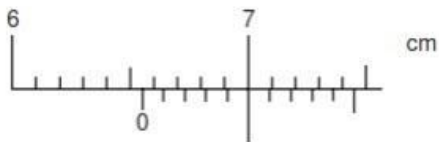
Physics Quiz

1. Least count of vernier caliper is

a.   1mm

b.   1 cm

c.   0.1 mm

d.   0.1 cm

2. The diagram shows part of a vernier scale.

What is the reading on the vernier scale?

a.   6.50 cm

b.   6.55 cm

c.   7.00 cm

d.   7.45 cm

3. Vernier caliper helps in measuring

a. External diameter

b. Internal diameter

c. Thickness and depth of narrow tubes

d. All of them

4. What is Newton's 2nd Law in equation form?

a. P = mv

b. s = d/t

c. Force of friction = ma

d. It cannot be written as an equation.

5. What is the reason for slipping while walking on ice?

a. None of these

b. There is a lot of friction on ice.

c. There is little friction on ice.

d. There is a large normal reaction.

6. What is the force of attraction between all heavenly bodies called?

a. Electrostatic force

b. Gravitational force

c. Weak force

d. Strong force

7. A solid ball and a cylinder roll down an inclined plane. Which reaches the bottom first?

a. The ball reaches the bottom first.

b. The cylinder reaches the bottom first.

c. They arrive at the bottom at the same time.

d. It depends on the relative diameter of the two

8. The height of tower when stone dropped from it reaches ground in 5s is

a. 130 m

b. 125 m

c. 150 m

d. 200 m

9. Gravitational force of earth is

a.   5.4 ms(-2)

b.   6.9 m s(-2)

c.   9.8 m s(-2)

d.   11.1 m s(-2)

10. When a body slides over another, the frictional force experienced by the body is known

as _____ friction.

a.   Sliding

b.   Rolling

c.   Static

d.   None of the above

APPENDIX B

SYSTEM USABILITY SCALE (SUS) QUESTIONNAIRE

Personal Information

Full Name: _____   **Age:** _____

Gender: ☐ Female   ☐ Male   **Class:** _____

_____

Usability Questionnaire

1- Strongly Disagree 2- Disagree 3- Neutral 4- Agree 5- Strongly Agree

S.No	Questions	1	2	3	4	5
1	I think that I would like to use virtual laboratory application frequently.					
2	I found the virtual laboratory application unnecessarily complex.					
3	I thought the virtual laboratory application was easy to use.					
4	I think that I would need the support of a technical person to be able to use virtual laboratory application.					
5	I found the various functions in virtual laboratory application was well integrated.					

6	I thought there was too much inconsistency in virtual laboratory application.					
7	I would imagine that most people would learn to use virtual laboratory application very quickly.					
8	I found the virtual laboratory application very awkward to use.					
9	I felt very confident using the virtual laboratory application.					
10	I needed to learn a lot of things before I could get going with virtual laboratory application.					