Blended Physics Laboratory Experiments and Teacher Education Students' Learning of Electricity and Magnetism

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This is to certify that the dissertation prepared by Zemenu Mihret Zewdie, entitled: **Blended Physics Laboratory Experiments and Teacher Education Students' Learning of Electricity and Magnetism**, and submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Physics Education, complies with the regulations of Addis Ababa University and meets the accepted standards with respect to originality and quality.

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Declaration

I declare that this dissertation is my original work and all the sources that I have cited or quoted herein have been duly acknowledged and referenced.

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Abstract

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The purpose of this study was to examine the effects of blended physics laboratory experiments on teacher education students' conceptual understanding, understanding of the nature of science, and attitude toward physics laboratory experiments in a laboratory course that included concepts of electricity and magnetism. The study used a non-randomized quasi-experimental mixed methods design with pretest-posttest. It comprised a total of 63 pre-service physics teachers enrolled at three colleges of teacher education, with 16 in the blended experiment group, 26 in the virtual experiment group, and 21 in the real experiment group. The first treatment group used a blend of real and virtual experiments; the second treatment group solely used virtual experiments; and the comparison group exclusively used real experiments. With the exception of the type of manipulatives utilized, similar experiments from the physics laboratory course were taught to all three conditions using a guided inquiry-based approach. Conceptual understanding test for electricity and magnetism, understanding of the nature of science questionnaires, and attitudes towards physics laboratory questionnaires were used to collect quantitative data. Besides, qualitative data were gathered from participants on their opinions regarding the instructional strategies, the mode of physics laboratory experiments, and potential enhancements. Data were analyzed using descriptive statistics, paired sample t-test, one-way ANOVA, and thematic analysis. Results showed that blended experiments significantly improved students' attitudes towards physics laboratories, while virtual modes of laboratory experiments promoted conceptual understanding. Despite slight mean differences in favor of the treatments, there was no significant difference in understanding of the aspects of nature of science between the treatment and comparison groups. The majority of participants preferred blended and virtual modes of experimentation over real ones, despite some participants raising concerns about access to computers, additional software training, and more practice time. The efficacy of the various modes of physics laboratory experiments could depend on factors other than the media per se, such as the type of instructional strategy, curricular materials, and additional learning time. It is recommended that further study be done using different methodologies on the efficacy of different modes of experimentation to resolve conflicting results and produce optimal learning.

Keywords: Attitude towards physics laboratory, Blended laboratory experiment, Conceptual understanding, Electricity and magnetism, Understanding of the nature of science

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List of Acronyms and Abbreviations

- AAPT American Association of Physics Teachers
- AREB Amhara Regional Education Bureau
- BEG Blended Experiment Group
- CTE College of Teacher Education
- EMCU Electricity and Magnetism Conceptual Understanding
- ESDP Education Sector Development Program
- ICT Information Communications Technology
- FCI Force Concept Inventory
- MOE Ministry of Education
- NAE National Agency for Examinations
- NOS Nature of Science
- NRC National Research Council
- NSTA National Science Teachers Association
- PhET Physics Education Technology
- PSPT Pre-service Physics Teacher
- REG Real Experiment Group
- STEM Science, Technology, Engineering, and Mathematics
- TGE Translational Government of Ethiopia
- VEG Virtual Experiment Group
- VNOS Views of Nature of Science

CHAPTER 1: INTRODUCTION

1.1. Background of the study

Science education is important for a country's overall development, including economic, social, political, and cultural aspects. Science contributes to technology in a variety of ways, and technology's impact on science is also fundamental. For example, a technologically advanced society makes informed decisions about contemporary concerns. These include concerns about, among others, climate change, energy crisis, genetic modification, global and national emergencies because of war, economic decline, and pandemics like COVID-19. Science and technology-based solutions are supposed to offer solutions to some of these issues (Kola, 2013; McFarlane, 2013; Holbrook, 2010; Drori, 2000). There is no longer any debate on the importance and necessity of science education. How to give high-quality science education at various levels of schooling is still being questioned and studied. This is due to the emerging consensus that the inadequacy of science education in many countries limits their capacity to carry out effective economic growth and development plans (Teferra et al., 2018; Joshi & Verspoor, 2012).

The International Council of Scientific Unions (ICSU) noted that developing nations confront greater challenges in science education than developed nations due to a shortage of teaching resources, laboratory facilities and equipment, computing and communications technologies, and skilled teachers, among others (ICSU, 2011). For example, many African countries are aware of the vital role that science plays in socioeconomic development, but the lack of skilled personnel, infrastructure, tools, and resources has hindered the quality of science education (Ogunniyi & Rollnick, 2015). The problem of science education is one that affects developed countries as well as less developed and developing ones (Wieman & Perkins, 2006). The authors noted that science lessons from elementary school to university often fall short of giving the majority of students a basic understanding of science that will enable them to function well in the 21st century, both personally and professionally.

Ethiopia, like other developing countries, needs quick improvement in science and mathematics education and appears to be ready to address development concerns in science and technology through its education and training policy. The Ethiopian government has made education a top priority in all of its development efforts, fully believing that quality education and training are both essential to human development and inseparably tied to broad-based economic growth and democratic governance (MOE, 2017; TGE, 1994).

Cognizant of this, science subjects are prioritized in the Ethiopian education system. However, the implementation of science education in Ethiopia has challenges at all educational levels (Teferra, et al., 2018). The authors pointed out that, among other things, the lack of competent academic staff members and the shortage of adequate and well-established laboratories seriously undermine the quality of science instruction. Researchers noted an excessive focus on content, lecture-dominated instruction, and a lack of equipment and resources, among others, all of which are attributed to the system-wide problem of science education (Alemu, 2015; Semela, 2010; Shibeshi et al., 2009; Bekalo & Welford, 2000). Besides, a study on teachers' practices of assessment for learning in science education reported that the education system had challenges linked to teacher-related variables, a lack of resources and facilities, and a lack of motivation and interest (Dessie, 2015). Based on the discussions so far, there is much evidence that students globally, and particularly in Ethiopia, perform poorly in science education.

Physics, as an element of science education, facilitates the development of a close relationship between science and technology, resulting in building of innovative and creative citizens (Sanchez

& Ponce, 2020). The subject has substantial importance for overall national development and helps secure the future needs of a country for scientific and technological competence (Bigozzi et al., 2018). It is evident to say that other sciences such as chemistry, agriculture, environmental sciences, biological sciences, engineering, medicine, and many others are reliant on the concepts and techniques developed through physics (Belay et al., 2016). It has impacted and is continuing to impact our lives in many aspects, such as developing our way of thinking, technological progress, economic development, and the diagnosis and treatment of diseases.

It has become difficult to deliver and maintain high-quality physics education, despite the fact that it is one of the disciplines that is prioritized in science education. It has been shown that conventional physics instruction that focuses on simple memorization and naive quantitative problem solving that does not result in understanding of physics concepts is ineffective (Gerace & Beatty, 2005; Sherin, 2001; McDermott & Redish, 1999). In addition, it has been shown that conventional practical work and experimentation focused on recipe-type strategies are inadequate at offering the improvements that are required (Rusanganwa, 2012; Schauer et al., 2008; Millar, 2004). It necessitates the development of a teaching and learning process, where the teacher is crucial as a facilitator, prepared to explain and challenge students with new scientific knowledge. Student difficulties in learning physics, as well as the problem of the quality of physics education, prompted the emergence and growth of physics education research (PER) as a discipline. However, the question of quality physics education is still a concern, which continues to the present time.

The current practice of learning and teaching in colleges of teacher education is more of a teacher-centered method (Teferra et al., 2018; Alemu, 2015; MOE, 2015). Because of this teaching approach, instructors are considered source of knowledge, which makes them dominant in the teaching and learning process. In this method of teaching, pre-service physics teachers take part in the teaching and learning process as an inactive participant, receiving information, storing it, writing a short note or memo, and reprocessing it for evaluation or assessment purposes. Despite continued research and the identification of different innovative teaching strategies, the quality of physics education remains in question at the College of Teacher Education (CTE) level (Worku & Alemu, 2021; Alemu, 2015). Many students have completed their study of physics courses with substantial conceptual understanding gaps, despite the efforts of physics teachers (Eshetu & Alemu, 2018; Cahyadi, 2004). That is to say, on the one hand, conventional teaching methods produce misconceptions and inadequate conceptual grasp of physics concepts, and on the other hand, many students continue to have inadequate explanations of physics concepts after receiving conventional instruction. This is because students learn very little from conventional lecture-type instruction, which does not encourage them to think for themselves in constructing their own meaning and explanation (Lasry et al., 2008).

Despite efforts to rectify the problem, there has been a decline in the quality of physics instruction in Ethiopia, according to several studies. For example, the composite mean scores in physics for grade 8 students were 35.32%, 32.2%, and 34.47% in the national learning assessments conducted by the National Agency for Examinations (NAE) in years 2004, 2008, and 2012, respectively (Belay et al., 2016; Woldetsadik, 2013). According to the reports of the first national learning assessment, physics had the lowest mean scores in grades 10 and 12, with 31.2% and 36.6%, respectively, when compared to English, mathematics, and other science subjects. In addition, only 10.1% and 16.7%, respectively, of students in grades 10 and 12, achieved a score of 50% or above (NAE, 2010). Similar to this, the second national learning assessment (NAE, 2014) also showed that students in grades 10 and 12 had the lowest achievement scores, 35.4% and 33.1%, respectively, in physics as compared to the baseline score of 50% (TGE, 1994). In 2014, grade 10 students' performance in physics was assessed, and it was reported that 14% and 2% of students received 50% and 75% of the attainable points, respectively (MOE, 2015).

According to the third national learning assessment for grades 10 and 12 (NAE, 2017), 4.6% and 7.4% of students scored 50% or higher in physics. In grades 10 and 12, 0.5% and 1.0%, respectively, of students received a physics score of 75% or higher. When achievement patterns across time were evaluated, grade 10 and 12 students performed significantly lower than in 2013. The availability of educational resources, accessibility of school facilities, school emphasis on academic performance, and student attitudes toward their teachers and the subject they are studying were a few of the many elements influencing students' achievement. Since they are at the foundational levels, working with primary level physics teachers is crucial to addressing the issue of the vicious cycle of poor quality that further deteriorates quality. According to Alemu et al. (2021), Ethiopian students have consistently scored below expectations because physics teachers lack understanding of the topic to teach effectively. According to the reports, there is a pressing need to take action due to the low achievement of students in physics including revising the mode of instruction and connecting the concepts to real-world situations. These and other similar studies indicate that the problem is widely recognized, and that efforts are being made to address it, but that ensuring quality physics education remains a challenge.

The Amhara Region Education Bureau (ARBE) annual report on the Certificate of Competency (COC) results of pre-service teachers at CTEs also illustrated problem of the quality of physics education. When the three-year (2017–2019) report was analyzed, students who achieved above 70% in integrated natural science courses were found to be below 50%. In addition, no student scored above 70% in physics in 2017, and there was only one student who scored above 70% in 2019 (AREB, 2019). The results can demonstrate the low achievement scores in the subject, though the examinations administered for the COC were not standardized. These findings provide a strong alarm for intervening with the problem by providing quality physics education via different strategies and mechanisms, such as quality physics experimental laboratories, using different alternatives.

It is no longer in question that laboratory experiments have played a significant and distinctive role in physics education and, when used properly, offer substantial learning benefits (Musasia et al., 2016; Vilaythong, 2011; Millar, 2004; Meester & Kirschner, 1995). Even though the phrases *laboratory work*, *experiments,* and *practical work* are sometimes used interchangeably, they do not all mean the same thing. Many researchers have examined the interrelationship between experiments, laboratory work, practical work, and scientific education didactics (Vilaythong, 2011; Bradley, 2005; Meester & Kirschner, 1995). Based on the works of Hodson (1988), Bradley (2005), and others, experiments are specialized types of laboratory work. Laboratory works are subsets of practical works, which are subsets of all instructional methods or teaching and learning methods used in science education. Ferreira & Morais (2018) contrasted the definitions of practical work provided by Hodson (1988) and Millar (2004), noting that the former is broad and encompasses any activity that requires students to be engaged. Whereas the latter defines practical work as any learning activity in science that involves students experiencing or examining materials or real objects. This includes direct representations of real objects or materials in a simulation or video recording. However, the authors suggested that the definition given by Lunetta et al. (2007) is more precise and closer to the definition of practical work in the present time. The presently accepted definition of *practical work* is all teaching and learning activities that can be classified as inquiry-based activities in which students actively participate (Ferreira & Morais, 2018).

There is substantial evidence that conventional practical work and laboratory experiments are ineffective in achieving laboratory education's intended goals (Chambers, 2014). If performed appropriately, laboratory experiments can be used for a wide range of purposes, including enthusing students about science and teaching them how to conduct scientific investigations (Hofstein & Lunetta, 2004). Besides, students will acquire essential skills in a wide range of methods of reasoning and the ability to make decisions regarding evidence in scientific arguments (Tytler, 2007).

The effectiveness of conventional practical work on students' learning outcomes has been extensively researched. One group of researchers evaluated the efficiency of practical work compared to classroom lectures and found positive results with various student learning outcomes (Shana & Abulibdeh, 2020; Musasia et al., 2016). Indeed, the comparison is not fair because the two sets of methods are not comparable because even the conventional laboratory requires a different design of activities, more time, more resources, and more participation than the typical lecture. As such, a positive effect on practical work and laboratory experiments in science classes is not unexpected. However, appropriate implementation is required to engage students with science through practical work and laboratory experiments. In a conventional laboratory experiment, a small number students will usually be engaged in the tasks that are assigned (NRC, 2005). If students merely follow the laboratory instructions during experiments without making any connections to the real world, the methods will be useless (Shana & Abulibdeh, 2020).

Additional studies revealed that conventional practical work had little impact on students' understanding compared to other innovative means by which students learn physics content (Holmes et al., 2017; Wieman & Holmes, 2015). This conventional approach causes confusion in student learning if not properly implemented (Hake, 2002). The sort of activity design and student engagement are more important than the technology and supplies employed. If the laboratory activities are designed to focus on simple manipulation of equipment and materials, memorizing experimental procedures, and collecting and analyzing data for report purposes, students become fatigued, fail to understand the concept being studied, and develop an unfavorable attitude (Vilaythong, 2011). Despite its drawbacks, the laboratory is still utilized in many schools and institutions for conventional practical work (Hofstein, 2017). Schools at all levels, colleges, and universities suffer from a lack of equipment and resources, bad infrastructure, a scarcity of qualified personnel, a lack of funding, and other challenges in many developing countries (Babalola, 2017). Some of these issues also impact students in developed nations who study physics through laboratory experiments (Ndihokubwayo, 2017; Hofstein & Lunetta, 2004). For instance, Hofstein & Lunetta (2004) pointed out the fact that many nations continue to advocate that teachers spend a significant amount of laboratory time performing managerial tasks rather than challenging students' conceptions and enabling them to investigate and test alternative explanations and hypotheses.

Scholars revealed that guided inquiry laboratories improved students' learning and retention (Irinoye et al., 2015), helped them develop more positive attitudes (Chatterjee et al., 2009), and enabled them to better understand the nature of science (Thompson, 2007). Of course, choosing the appropriate level of inquiry is a contentious issue. Many authors, however, identified a relationship between guided inquiry practices and increased levels of teacher help in the form of questions that prompt students to consider the next steps after observation (Blanchard et al., 2010). Despite its enticing nature, scholars identified contradictory results regarding the effects of guided and open inquiry levels on student learning outcomes (Zion & Mendelovici, 2012). Inquiry-based teaching and learning with varying levels of autonomy for students spans a wide range of strategies, from structured and guided teacher-directed inquiry to open, student-directed inquiry (NRC, 2000). According to Zion & Mendelovici (2012), guided inquiry helps students understand the nature of scientific knowledge, master scientific skills, minimize time waste, reduce student stress due to adverse outcomes, and minimize their fear of the unknown. On the other hand, proponents of open inquiry claim that it provides a higher level of inquiry by allowing students to become more aware of the nature of scientific knowledge and acquire enhanced inquiry abilities and practices. Other authors, on the other hand, claim that frequent engagement in open inquiry has a negative impact on science success (Aditomo & Klieme, 2020; Mayer, 2004).

It has been reported that the implementation of practical work and laboratory experiments in Ethiopian context is also not effective, both in secondary schools (Nigussie et al., 2018; Daba & Anbesaw, 2016) and at higher education levels (Engida, 2012The authors noted that insufficient laboratory facilities, a lack of qualified laboratory technicians and teachers, and inadequate attention from the relevant stakeholders to practical activities were anong the challenges. In their review of the literature, Bekalo & Welford (2000) stated that the inability to incorporate important practical experience and inappropriate and irrelevant methods led to development of the new Education and Training Policy and other implementation documents such as frameworks and ESDPs. Moreover, the policy was developed in response to inadequate supply of facilities, overcrowded classes, inadequate teacher preparation, and a shortage of books and other teaching resources, all of which suggest a low quality of education delivered (TGE, 1994). As a result, it promotes the development of problem-solving abilities and culture in educational content, curricular structure, and approach, with a focus on scientific knowledge acquisition and practicum. Following the policy's launch, several supporting documents were developed and distributed in preparation for implementation. Notwithstanding the launch of many initiatives and supporting documents for the education sector, Ethiopia continues to face a major problem in terms of education quality at all levels (Goshu & Woldeamanuel, 2019; Teferra et al., 2018).

Among the factors that had significant correlations with student achievement were the availability of instructional materials, provision of school resource infrastructure, instructional time, teacher shortage, students' attitudes towards the subject, and teacher related variables (MOE, 2015; NAE, 2010). Thus, offering information and communication technology (ICT)-based alternatives to laboratory teaching and equipping pre-service physics teachers with the necessary knowledge and skills may help alleviate the challenge of ensuring quality physics instruction.

As a result of this quality issue, there is increasing concern about improving the quality of physics education. However, the teaching-learning process in schools remains predominantly teacher-centered, with too much emphasis on content and little evidence of active learning, inquiry processes, or higher-order thinking skills (Gbre-eyesus, 2017; Alemu, 2015). Enhancing instruction quality includes not only installing the necessary equipment and infrastructure but also improving teaching quality. Among other factors, teachers are critical elements for quality education (Ahmad, 2014; Darling-Hammond, 1995), so does for quality physics education. The Ethiopian Education Roadmap, under the theme of Teacher Preparation and Development (Teferra et al., 2018), cited McKinsey and Company's assertion that the quality of the education sub-system cannot surpass the quality of its teachers. If the problem starts at the primary level, this leads to a vicious cycle of low quality that leads to a further decline in quality physics education. It is essential to prepare well-educated and trained primary teachers in order to relieve the situation. They are the ones who are required to lay the foundation for children and youth to pursue additional education later in life. Because children in their early years are active investigators of their surroundings, primary teachers are required to spark the interest and curiosity of children and teenagers using inquiry-based approaches.

However, within colleges of teacher education, there are still gaps in teacher educators' practical experience and teacher trainees' subject knowledge (Teferra et al., 2018; MOE, 2015). At this point, it is reasonable to argue that laboratory experiments and activities play a crucial role, if used effectively, in addressing the issues of effective physics instruction at all levels of the education system. In CTEs, laboratory work was a key part of the physics education curriculum. According to Babalola et al. (2020), incorporating laboratory experiments in physics classrooms helps students understand concepts, reinforces theory, develops professional skills, explores and illustrates physics laws, motivates students, and nurtures students' self-improvement and life skills. But, the actual practice is less likely to achieve these objectives because little attention is given to the practical aspects of physics (Teferra et al., 2018; MOE, 2015).

According to Hofstein (2017)Lunetta et al. (2007), laboratory experiments are a way of helping students to learn through understanding and helping them engage in the process of learning by doing by constructing their own knowledge. Experiments in physics classrooms can promote learners' deep conceptual understanding of physics concepts (Omosewo, 2006), develop skills to infer and interrelate multiple concepts (Okono et al., 2015), help to encourage for active participation and enhance critical thinking by catching students' interest and motivation (Babalola, 2017). Besides, experiments enhance students' scientific skills (Ndihokubwayo, 2017), and facilitate the establishment of new theories, disprove existing theories, or redefine theories (McDermott et al., 2000). However, the recipe-based experiments were found to be insufficient to enhance students' learning because they required expository-type instruction in order to attain a known answer to a problem under investigation (Baloyi, 2017).

Physics as a subject is still perceived as abstract, difficult, unappealing, and less applicable to the world of work, which leads to the formation of unfavorable attitudes about the subject (Mbonyiryivuze et al., 2019; Veloo et al., 2015; Semela, 2010). Due to this, many students find learning physics to be frustrating, and the majority of those who were assigned to study physics were blamed for their lack of interest and poor performance (Hamelo, 2016). The author claims that the way teachers teach physics and the difficulty of the subject are the main reasons students dislike it. The learning of courses such as mechanics, heat, optics, electricity, and magnetism, among others, was largely based on the conventional chalk-and-talk method and focused on memorization of formulas and definitions that could not prepare students for applications in the real world (Semela, 2010; Bekalo & Welford, 2000). For instance, Kapucu (2016) pointed out that students could perceive physics as unimportant to their lives and dislike it due to the numerous formulae and equations that need to be memorized in physics lessons, the idea that physics is a challenging topic, a lack of competence in mathematics, and failing physics tasks.

Electricity and magnetism concepts are among the topics in physics that are abstract and challenging compared to, say, mechanics courses (Mbonyiryivuze et al., 2019; Gunstone et al., 2009). Laboratory experimentation is very important to help students learn these abstract concepts. However, the challenges related to real or physical laboratories shifted the attention of scholars to ICT-enhanced laboratories such as virtual and blended (Daineko et al., 2016; Dyrberg et al., 2016). For instance, Daineko et al. (2016) stated that a variety of factors, like being overburdened with other studies, insufficient funds, a lack of time, outdated equipment, maintenance issues, and others, may cause us to focus more on using ICT-supported laboratories. These types of alternatives are essential not only in regular classes but also in times of education crises such as the COVID-19 pandemic, conflicts, and others. A growing body of research demonstrates the use of virtual and different forms of blended experimentation models to engage students in the teaching and learning process (Hamed & Aljanazrah, 2020).

The emergence of ICT has brought alternative modes of physics experimentation such as blended and virtual simulations, for example, in helping students visualize the physics concepts to understand them easily (Zacharia & Anderson, 2003) and to imagine abstract events and processes that are difficult in a real laboratory (Gunawan et al., 2018). However, the effect of technology-enhanced learning should be studied in order to know its effects on physics instruction before large-scale investment. For example, the plasma-based instruction that was introduced in Ethiopian secondary schools encountered many problems despite its importance. Plasma-based instruction is one of the Educational TV programs that use the installation of satellite-receiving devices known as Plasma Display Panels in every classroom, the setup of a computer network system, and the installation of satellite TV program transition systems at the center of the Educational Media Agency. From the outset, it was intended to provide quality and equitable education. But, research has shown that it has drawbacks on the part of teachers, students, and parents.The difference in teaching and learning philosophies that existed between teachers and students, awareness of plasma-mode instruction, utopian and dystopian viewpoints in general, and dissatisfaction of students because of language difficulty and a shortage of time for discussion were the problems identified (Berhanu, 2013; Getnet, 2008).

Though there is no general consensus regarding the educational goals of and how to assess those goals for physics laboratories, Trumper (2003) summarized the goals and purposes of physics laboratory work up to the 1970s as follows: skills, concepts, the nature of science, and attitudes. Later on, the American Association of Physics Teachers (1998), informed by a constructivist perspective, published a new set of goals for the physics laboratory: conceptual learning, the art of experimentation, developing collaborative learning skills, experimental and analytical skills, and understanding the foundations of knowledge in physics. Singh (2014) claimed that there are many goals associated with experimentation in physics, and grouping these goals into some broad categories can help with a better understanding of the goals. The author summarized the goals of the laboratory into six broad categories: conceptual understanding; interest, motivation, and other affective values; procedural understanding; practical skills; process skills; and scientific attitudes. Other institutions, such as the National Research Council (NRC), have identified physics learning goals that have been ascribed to practical work and laboratory experiments and activities (NRC, 2005). This includes enhancing mastery of subject matter, boosting understanding of the intricacy and ambiguity of empirical work, promoting scientific reasoning abilities, developing practical skills, enhancing the understanding of the nature of science, fostering interest in science and learning science, and strengthening teamwork abilities. These categories of laboratory work goals helped the researcher decide to focus this research on the effectiveness of physics experimentation, with a particular emphasis on conceptual understanding, understanding of the nature of science, and attitude toward the physics laboratory.

Since the beginning of systematic science instruction in the nineteenth century, the laboratory has been a major element of science education (Oser, 2013). A laboratory, according to Hofstein & Kind (2012), is an experience in a school setting in which students engage with equipment and materials or secondary data sources to observe and analyze the natural world. However, in the early years of science experiments in school, laboratories were merely places where students could practice or validate material received during lectures or from textbooks. The development of laboratories as environments for study and inquiry took a long time and is still underway (Oser, 2013). When we look at its evolution, we can see that psychologists in the 1960s and 1970s made significant contributions to experimentation in science education. The process continued, but the empiricist approach, which included following the instructions, finding the correct answer, and manipulating equipment, was criticized for putting too much emphasis on the scientific method.

In the constructivist approach, laboratory learning is viewed as a socialization towards scientific culture, and students are encouraged to engage in metacognition, which requires them to internalize their own thought processes as well as those of their peers (Oser, 2013; Hofstein & Kind, 2012). Despite all of these reform initiatives throughout the years, problems persist. In practice, theories like inquiry and constructivism were difficult to incorporate. That is, teachers favored the simpler cookbook method, in which students conduct inquiries as if they were following a recipe, and teachers undervalued students' abilities to manage the high cognitive demands of actual investigations (Hofstein & Kind, 2012). In response to these issues, the authors advocated for the incorporation of ICT in the science laboratory. They reported that integrating ICT in the laboratory improved students' conceptual understanding of science, yet the extent to which ICT is used in various school laboratories differs.

The term *manipulative* has been broadened to include both real and virtual tools as a result of the incorporation of ICT into the educational system. Manipulatives are multimodal tools that represent ideas in a variety of ways and can be used to enhance and improve understanding among students (De Jong et al., 2013). According to the authors, both real and virtual manipulatives can attain similar purposes, such as developing teamwork skills, examining the nature of science, promoting conceptual understanding, fostering interest in science, and developing inquiry skills, but they also have specialized affordances. As a result, it is essential to consider the characteristics of real, virtual, and blended modes before determining which one benefits student learning in a physics laboratory. As a result, the present study examined the instructional efficacy of virtual laboratories, which are computer-based simulations of real-world investigations. In keeping with the previously indicated benefits of technology integration, virtual laboratories were expected to save time on tedious laboratory duties and allow students to focus on the theory underlying the research, as well as its relationship to the design of the experiment.

Real and virtual physics experiments have their own benefits for learning physics concepts; however, drawbacks have been reported when either mode of experimentation is implemented in the physics instruction. Some studies, for example, show that virtual laboratories are educational hindrances (Sicker et al., 2003), whereas others see them as valuable supplements to learning in real laboratories (Finkelstein, et al., 2005). Because of this, some researchers argue that blended experiments can take advantage of either method alone since combining the two modes of experimentation may boost students' skill acquisition level and raise their satisfaction (Brinson, 2015). In addition, studies conducted in the domains of light and color (Olympiou & Zacharia, 2012) and light and shadows (Olympiou & Zacharia, 2014) revealed that a blended combination of real and virtual experimentation enhanced students' conceptual understanding. However, these scholars suggested that further research should be conducted using different designs, educational levels, contexts, age levels, domains, and other issues in order to get a complete picture of how the combination takes place and arrive at safe conclusions.

In sum, experimentation is integral to physics instruction, and the quest for alternative and up-to-date innovations in instruction is essential. It is not only the mode of experimentation but also the instructional strategy followed can influence the effectiveness of experimentation in physics. The inclusion of practical work and laboratory experiments in the physics curriculum could not assure their effectiveness in improving students' scientific knowledge. The instructional strategy employed can also affect students' learning. We have to ask whether students learn the way it was intended for them. The curriculum designed and the implementation process should resolve the common criticism of recipe-type practical work in teaching practical courses (Millar, 2004). The laboratory has played an important role in student learning for well over a century (Meltzer & Otero, 2015), unfortunately, many existing laboratories, which haven't advanced much since from the late 1980s, have been criticized for their archaic cookbook approach, which is ineffective in teaching high-end skills (Bao & Koenig, 2019). An inquiry-based approach is one of the research-informed teaching strategies that is aimed at enhancing students' learning by improving their understanding of the nature of science, conceptual understanding of physics concepts, and attitude toward physics experiments (Fan, 2015). Though there are different levels (open, guided, structured and confirmatory) of inquiry-based learning in physics experiment activities, guided inquiry-based learning is selected for the intervention of this study. The selection is made based on reviewing the literature and looking at the nature of the teaching and learning practices in CTEs.

The way that science laboratory experiments are presented, how they are conducted, and how they are facilitated can all differ, as can how well students learn and how they choose to learn (Basey et al., 2008). The authors further noted that varying combinations of laboratory characteristics are expected to lead to different outcomes in terms of student learning. Physics practical work and laboratory experiments should be planned and carried out using the ideas of constructivist learning theory. This is because laboratory experiments are regarded by constructivist theory as being more than merely knowing how to do something; they are an essential part of understanding science itself (Basey et al., 2008; Shiland, 1999). An inquiry-based laboratory, guided by constructivist notions in which students actively engage in the design and carrying out of an investigation, is valuable for drawing conclusions for a question posed. Informed by constructivist learning theory, the inquiry-based laboratory learning approach is advocated by many scholars. As a result, other than the types of experiments used, the instructional strategies employed can affect the learning outcome.

Studies on blended modes of physics laboratory experimentation were reviewed, and inconsistent results were found (Wörner et al., 2022; Brisnson, 2015). Moreover, others call for a comprehensive study with large sample sizes, many outcome variables, varying subjects and topics, different data gathering tools, different designs, education levels, and others to develop a framework. Others criticize that the gains from blended learning were not from its nature but rather from extra time for work, additional instructional resources, instructional strategies, and teacher-related variables (Pineda, 2015; Means et al., 2009). After reviewing various research articles, many authors call for further research. In sum, there is practical, theoretical, and empirical evidence to conduct the effectiveness of blended physics laboratories on pre-service physics teachers learning using guided inquiry-based learning.

The purpose of this study was to search for a better laboratory learning environment that can improve understanding of the nature of science, conceptual understanding, and attitudes toward physics laboratories for PSPTs learning electricity and magnetism experiments. In order to improve physics learning on the above-noted dependent variables, laboratory manipulatives that engage pre-service physics teachers in blended, virtual, and real modes of experimentation were used in this study. This strategy is in line with changes in policy and curriculum that promote student-centered learning.

1.2. Statement of the problem

The findings of the national learning assessments for grades 8 (NAE, 2008) and 10 & 12 (NAE, 2014, 2017) showed that physics achievement was below the minimum score required for students to qualify for promotion to the next level. Since children in these grades are the ones who would enroll in CTEs after completing high school, the issue would be in a vicious circle. Primary physics teachers in Ethiopia lack the requisite physics knowledge to teach students effectively, according to a study by Alemu et al. (2021) that examined the knowledge gap between intended and attained in Ethiopian teacher education. The scenario amplifies the cycle of low achievement and will cause the next generation of Ethiopian students to perform below average in physics. The availability of educational resources, the accessibility of educational facilities, and student attitudes toward their teachers and the subject they are studying all have an impact on student achievement in physics (NAE, 2017).

In order to overcome the current quality problems in physics education, focusing on elementary-level teachers may curtail the vicious loop problem since this should be done initially with teachers, especially those at the primary level. This can be achieved through incorporating practical applications and laboratory exercises for helping PSPTs in understanding physics concepts, and fostering the development of scientific inquiry skills. Engaging PSPTs in innovative practical work and laboratory experimentation strategies is one of the approaches to enhancing the quality of physics learning as one of the science subjects. The teaching and learning process in the laboratory courses was determined to be ineffective, despite the fact that laboratory experiments are included in physics laboratory courses in CTEs in recognition of their distinctive role (AREB, 2019).

Many agree that experiments are an indispensable part of learning physics concepts and gaining skills; however, various research findings report that there are many problems with using real experiments (Saudelli et al., 2021; Daineko et al., 2016; Dyrberg et al., 2016). For instance, Daineko et al. (2016) noted that real laboratories may not be available to students for several reasons, including safety concerns, time restraints, budget constraints, outdated equipment, maintenance problems, and visualization issues with small or large objects. It is claimed that Ethiopian science education suffers from a severe lack of instructional resources and tools, a shortage of experienced teachers and laboratory assistants, and a reliance on memorization techniques, among other issues (Engida, 2012; Eshetu et al., 2009). In the Ethiopian context, the problems related to practical work and laboratory experiments in learning science concepts and skills are also problems of physics instruction.

Therefore, in order to mitigate the drawbacks of real laboratory experiments, it is essential to look for alternative ways of physics laboratory experimentation. It is recommended that physics teacher make extensive use of a variety of technological resources to support inquiry-based learning (Ezeudu et al., 2013; Isman et al., 2007). Thus, inquiry-based physics experimentation that is informed by the constructivist perspective should be used, which helps engage students in the process of constructing knowledge (Wästberg et al., 2019; Ünal & Özdemir, 2013). Because the advent of information communication technology (ICT), virtual interactive simulations that support inquiry-based learning, such as Physics Education Technology (PhET), have been introduced to physics education.

Physics education research focused on different modes of experimentation yielded contrasting results regarding the benefits of real and virtual experiments. Some scholars have found that virtual simulations can provide better or at least equal learning environments with real laboratories in physics learning (Chini et al., 2012; Zacharia & Olympiou, 2011). In addition, studies conducted by Finkelstein et al. (2005) and Zacharia (2007) reported that the use of virtual experimentation helped student learning more than real experimentation. These authors asserted that virtual simulations play significant roles in the learning of physics by offering chances to various benefits. This includes providing opportunities for experiential learning; giving interesting and motivating tasks for students to explore; fostering active classroom involvement through discussions; developing students' problem-solving abilities and critical thinking; and opening up a wide range of possibilities (Oidov et al., 2012). In contrast, studies conducted by different authors (Zacharia & Olympiou, 2011; Zacharia & Constantinou, 2008; Triona & Klahr, 2003) revealed that the use of virtual and real experimentation benefited equally.

Other scholars, such as Jensen (2014) and Lindwall & Ivarsson (2010), reported that virtual simulations have unfavorable results because they tend to create virtual worlds that encumber students' development of links between objects and events to theories and models in physical reality. Virtual experimentation in physics deprives students of hands-on manipulation of physical materials (Hofstein & Lunetta, 2004) and should be used when real experimentation is unavailable, too expensive, too complicated, the experiment is unsafe, the experimental procedures are too intricate, or there are serious constraints (Zacharia & Constantinou, 2008). It is argued that not only virtual simulations but also scientific theories or models were recognized as merely an *approximation* to physical reality since they are based on assumptions, simplifications, and limitations that might not be valid in a practical situation (Bernhard, 2018). The findings of other research still revealed that the use of real experimentation benefited student learning more than virtual experimentation (Gire et al., 2010; Marshall & Young, 2006).

Meanwhile, using simulations in physics laboratories is not without its challenges. Because of this, another group of researchers who are focused on blended approaches interplay between advocates of real experiments and virtual experiments (Gumilar et al., 2019; Zacharia & Michael, 2016; Olympiou & Zacharia, 2014). These authors claimed that blended experiments are solutions that minimize the shortcomings of real and virtual experiments since each of them has its own affordances. It seems to be more conducive than the use of real experiments and virtual experiments alone; however, it was suggested that further research should be conducted for better learning outcomes among learners (Olympiou & Zacharia, 2014). Researchers who reported favorable outcomes from combined experiments are skeptical of their results, find it difficult to state clearly what supports the combination approach, and appear to maintain a middle way without convincing reasons (Brinson, 2015; Toth et al., 2014).

Many of the positive effects of blended physics laboratory experiments were reported in contexts with well-organized innovative instructional strategies and validated curriculum materials, such as The Physics by Inquiry curriculum developed by McDermott et al. (2000), as pointed out by Zacharia & Michael (2016) and Olympiou & Zacharia (2012). The results of a systematic review of 42 experimental studies combining real and virtual experiments revealed that the designs and implementation conditions varied among studies, the primary studies were inadequate, the reporting was of low quality, and seven publications did not specify the study design (Wörner et al., 2022). It might be claimed that these conditions may influence how participants learn, which in turn may influence the research outcome. It is indeed challenging to judge whether the blended approach or other factors related to the design process brought about a difference in students' learning outcomes (Means et al., 2009).

There has been limited research conducted regarding different modes of experimentation in physics education in the Ethiopian context. Kassa and Damtie (2007) investigated the effects of computer-simulated direct current circuit physics lessons on group interaction, achievement, practical skills, and attitude in first-year physics undergraduate students. The authors divided the students into two groups using random sampling: a virtual laboratory group and a real laboratory group. The instruments used to gather the data were questionnaires on group interaction and attitudes toward a particular type of experimentation, as well as achievement tests (which measured mastery of concepts and skills). The results disclosed that there were no significant differences between the treatment and comparison groups in terms of practical skill, group interaction, and attitude, but there were significant differences in their conceptual understanding of concepts. Since the authors classified one section of students into treatment and comparison groups, one can anticipate a high level of contamination in the research due to treatment diffusion.

Plasma-based instruction has been incorporated into the Ethiopian educational system as a method supported by technology. Despite benefits, studies showed that the use of plasma-based instruction was at incompatible with its intended purpose (Getnet, 2008). In addition, it was said that its philosophy went beyond that of the classroom teachers and the students' learning (Berhanu, 2013). This implies that appropriate readiness and familiarization with new innovations are mandatory before large-scale implementation.

Many empirical studies have also been conducted to determine whether real experimentation (RE) or virtual experimentation (VE) is best across a variety of science topic domains. The results from this research showed that there are some instances in which using VE would seem to be equally advantageous to student learning as RE (Triona and Klahr 2003; Klahr et al. 2007; Zacharia and Constantinou 2008; Zacharia and Olympiou 2011). Other authors reported higher benefits to student learning than RE (Zacharia et al., 2008; Zacharia 2007; Finkelstein et al., 2005), or vice versa (Marshall and Young 2006). Some scholars argued that conducting experiments virtually might deprive students of the chance to handle real materials, which is essential for their learning (Zacharia et al., 2008). On the other hand, proponents of using virtual experiments said that manipulation rather than physicality by its very nature may be the essential element of instruction (Klahr et al., 2007; Triona & Klahr, 2003).

Other researchers have found positive outcomes for the blended approach and recommended blending the two modes of experimentation rather than employing either one alone (Gumilar et al., 2019; Zacharia and Michael, 2016; Toth et al., 2014; Jaakkola et al., 2011; Olympiou & Zacharia; 2014). On the other hand, Marino (2018), Chao et al. (2016), and Darrah et al. (2014) have found no statistically significant differences between the groups of participants who were taught in a blended laboratory and other groups. So, the effectiveness of blended laboratory experiments is still a subject of debate and ongoing research (Worner et al., 2022; Brinson, 2015). For instance, Brinson (2015) claimed that the outcomes of blended laboratory experiments are inconsistent and that there is currently no agreement over the optimal procedures. According to a review study by Means et al. (2009), the time spent on tasks, the instructional materials utilized, and the instructional strategies employed matter more than the type of media used per se in producing positive outcomes of blended learning.

In empirical studies focused on laboratory experimentation, conceptual understanding was the most frequently examined outcome variable in terms of learning outcomes (Worner et al., 2022; Brinson, 2015). However, it was unable to find earlier studies that measured understanding of the nature of science aspects, and there were few studies that measured attitudes towards laboratories. In physics education, conceptual understanding is one of the most crucial learning objectives (Worner et al., 2022). The overall learning gains measured from learning using laboratory experiments can be influenced by student attitudes towards different modes of experimentation, such as real experimentation, virtual experimentation, and blended experimentation (Pyatt & Sims, 2012). According to scholars, educating students about the nature of science can help them grasp the concepts covered in science classes and enhance their academic achievement (Sardag et al., 2014; Tanel, 2013). The type and quality of science inquiry activities used in science classrooms can vary depending on the NOS level of the teachers. Therefore, having a deeper understanding of NOS concepts helps teachers acknowledge inquiry activities that are less structured and more student-oriented.

In conclusion, the researcher for the current study was inspired to examine the efficacy of a blended approach to experimentation by recognizing the theoretical, empirical, and practical significance of the many forms of physics laboratory experimentation. Theoretically, real and virtual experiments have a lot in common in terms of the affordances they may offer for conducting experiments, including the ability to manipulate materials, offer direct observations, and expose participants to experimental techniques. They do, however, carry a variety of affordances. Along with this, it should be explained about the necessity of using both in a laboratory setting and why one should be chosen over the other depending on which learning purpose is better met by a real and virtual experiment affordance.

Empirically, the results of earlier investigations on the efficacy of laboratory experiments in blended physics are not conclusive. The positive aspect is that many scholars have claimed its potential to support students' learning of physics in a variety of ways. Given that this is an emerging area of study, even authors who have achieved successful outcomes are recommending further investigation. Additionally, it was noted by researchers who reviewed earlier studies that the context in which the studies on the topic were conducted was multifaceted making it difficult to determine whether the favorable outcome was directly related to the blending. Many of those studies that showed positive results did not control for variations in instructional techniques, curricular materials, time on task, prior experience, and other factors.

Practically, due to resource constraints, poor infrastructure, a lack of skilled staff members, and other considerations, the Ethiopian educational system has various challenges when it comes to practical work and laboratory experiments in physics, similar to other regions of the world. To improve the learning of physics in CTEs, offering technology-enhanced laboratory alternatives such as blended physics laboratory experiments may be a viable choice. There has been little research done on the effects of blended laboratory experiments on PSPTs' physics learning, aside from the mixed results found with blended experiments. In low-income nations like Ethiopia, where lecturing has a strong tradition and practical work and laboratory experiments are rarely present or used, there is a dearth of empirical research reporting the efficacy of blended physics experiments. To address the low achievement of students in physics, looking for alternate laboratory experimentation methods seems unquestionable.

The following is a brief explanation of the problem statement for the current study. First, it is evident that blended laboratory experiments combine the benefits of real and virtual experiments, thereby improving the execution of effective physics teaching. However, no conclusive findings regarding the outcomes of the studies have been established. The researchers who reported positive outcomes with blended laboratory experiments did not control a wide range of factors, including instructional strategies, instructional resources, the role of researchers, and time on task. In addition, many academics recommend that since blending real and virtual studies is still a relatively new strategy, continuing research with a variety of options should be conducted to aid in the development of a unified framework. In the context of the country where the study was conducted, this study is important in addressing the challenges with physics education that have been noted as well as potential challenges of implementation regarding technology-based laboratory education. Additionally, the researcher has taught physics at CTEs for more than 10 years; therefore, the researcher was inspired to conduct the current study in an effort to contribute to a drop and alleviate the challenge of low achievement in physics education.

Thus, the current study fills a research gap on the effectiveness of blended physics laboratory experiments on pre-service physics teachers' learning in contexts where there is a very low tradition of innovative instructional strategies and curricular materials. Accordingly, the present study attempts to investigate the efficacy of blended physics experimentation on pre-service physics teachers' conceptual understanding, understanding of the nature of science, and attitude towards physics laboratories.

1.3. Objectives of the study

In this study, it was anticipated that pre-service physics teachers would achieve conceptual understanding, understanding of the nature of science, and a positive attitude toward physics laboratories when taught using a blend of real and virtual laboratory experiments. The participants were helped by a guided inquiry-based teaching method with instructional material prepared for the purpose of the study on a specific topic of electricity and magnetism to PSPTs in order to encourage this development. The main objective of the current study was to examine the effectiveness of blended physics laboratory experimentation in comparison to virtual and real experimentation for PSPTs' learning of electricity and magnetism. In line with this main objective, the following specific objectives were drawn to answer the research problem:

1. Examine effectiveness of blended mode of laboratory experimentation on pre-service physics teachers' conceptual understanding of electricity and magnetism concepts in contrast to virtual and real experimentations.

2. Determine effectiveness of blended mode of laboratory experimentation on pre-service physics teachers' understanding of the nature of science in comparison to solely virtual and real laboratory experimentation.

3. Examine effectiveness of blended mode of laboratory experimentation on pre-service physics teachers' attitudes towards the physics laboratories when completing a physics laboratory course as compared to solely virtual and real ones.

4. Examine the influence blended/virtual/real modes of physics laboratory experimentation on physics learning and what are participant opinions and comments towards it.

a) Investigate how PSPTs' learning is influenced by blended/virtual/real modes of physics laboratory experimentation.

b) Analyze the opinions of participants towards blended/virtual/real laboratory experimentation.

c) Examine participant comments to help enhance the mode of laboratory experimentation used.

1.4. Research questions

In this study, PSPTs used a real, virtual, and blended modes of physics laboratory experimentation to learn about the physics concepts of electricity and magnetism in an experimental laboratory course. The treatment and comparison groups received instruction using guided inquiry-based learning as the instructional strategy. The main research question was whether PSPTs would learn physics in a blended approach more effectively than they would have through solely virtual and real experimentation. This question was further divided into the following five questions in order to be answered successfully:

1. Is there a statistically significant difference between the treatment and comparison groups on the conceptual understanding of electricity and magnetism concepts?

2. Do blended experimentation in laboratories, compared to solely virtual and real laboratory experimentation, alter pre-service physics teachers' understanding of the nature of science?

3. What changes would result in pre-service physics teachers' attitudes towards the physics laboratory when learning experimental physics using real, virtual, and blended modes of experimentation?

4. How do the mode of physics laboratory experimentation utilized influence PSPTs' physics learning and what are their opinions and comments towards it?

a) How do blended/virtual/real modes of experimentations influence PSPTs' physics learning?

b) What are participant opinions of the blended/virtual/real physics laboratory experimentations?

c) What suggestions do participants have for improvement of the mode of experimentation used?

1.5. Significance of the study

It is fact that several Physics Education Research (PER) studies worldwide have been shown that a laboratory course sequence that includes both real and virtual laboratory experiments can be more effective than either alone. However in the Ethiopian context, PER is at an early stage, so there is very few, if any, study in the area that blended physics experiments with virtual experimentation on the teacher education students' learning of electricity and magnetism. Besides, studies conducted in the area revealed mixed findings. Though similar findings are well documented in the area, this dissertation as a whole is new investigation at least in its context of the study, multifaceted and comprehensive approach to the research problem and provided very interesting results which give new insight into the mechanisms of blending hands on physics experiments with virtual realities in physics laboratories.

The findings of this study might be used as a reference or as an initial investigation of the effects of different laboratory manipulatives on pre-service science teachers' physics learning, namely conceptual understanding, understanding of the nature of science, and attitudes towards physics laboratories. That is, researchers in the area can use it as a reference either to extend it or approach it from a different perspective. Physics teacher educators can use it to determine the appropriate physics laboratory manipulative when it is available to help pre-service physics teachers enhance their physics learning. Additionally, the results of the current study may be useful in supporting physics teacher educators, instructional designers, and educational authorities in making informed decisions in order to provide alternate approaches to physics laboratory experimentation. This could enhance physics education at all levels of the educational system, including colleges of teacher education, secondary schools, and primary schools. In particular, the findings of this study could have the following significance:

- Offers insights to physics teacher educator and physics education researchers regarding effectiveness of different modes of physics laboratory experimentation.
- Benefit students at different levels by offering alternate ways to laboratory experimentation when necessary, such as during crises like COVID-19 and other challenges in educational institutions.
- Provides additional way forward for physics educators, education policy makers and authorities to apply informed decisions when using ICT opportunities in education.
- Serves as additional resource for individuals who are interested in conducting further future researches in the area of physics laboratory education and ICT supported instruction.
- Provide additional insights for the scientific community in helping to calm down continued debates regarding the effects of blended, virtual and real physics

experimentations in physics learning so that consensus could be achieved when various researches in different contexts, methods and domains are conducted.

In sum, the present study offers contributions to the physics teaching and learning scientifically to PER, adds to the efforts of strengthening physics education and help to create alliance with initiatives working in the area, as a starting point in Ethiopia since PER works are at an infancy stage, provides support for using PhET sims in Ethiopian CTEs' physics classrooms.

1.6. Delimitation of the study

The study was conducted at three CTEs in the Amhara region. These research sites served as the laboratories where the quasi-experiment was carried out in order to examine the efficacy of the blended mode of laboratory experimentation. However, a random sampling technique was used to assign the CTEs to either the treatment group or the comparison group. Based on factors like accessibility, batch availability, laboratory facility, and laboratory course, the purposeful sampling technique was utilized to choose study sites and participants.

The study adopted a nonequivalent comparison group's pretest-posttest quasi-experimental employing mixed methods research design. An attempt was made to collect both qualitative and quantitative data. The outcome (dependent) variables measured in order to examine the effectiveness of the intervention were conceptual understanding, understanding of the nature of science, and attitude towards the physics laboratory experiments. Indeed, these are very limited learning outcomes from physics laboratory experimentation. Other outcome variables were not treated in this study because of the limited time of study on the part of the researcher and because the colleges' program was very tight to compensate for classes missed during the COVID-19 pandemic. The study would have been comprehensive if many variables had been treated.

The participants selected for the study were second-year pre-service teachers enrolled in the regular program of linear physics modality in 2013 E.C. (2020/2021 G.C.). There were no first-year entrants due to the government's plan to change the physics diploma program. Because there were inadequate materials and equipment available at research sites to conduct experiments, Experimental Physics III was not also chosen as an intervention curricular material. Though the curriculum for pre-service physics teachers embraces Experimental Physics I (Phys 112) and Experimental Physics III (Phys 311), the Experimental Physics II (Phys 211) laboratory course was selected as intervention material. This was due to its applicability in terms of the availability of real materials and equipment, the convenience of employing virtual manipulatives, and the availability of cohorts at research facilities. Based on the recommendations obtained from different theoretical perspectives, the nature of the intervention, and the results of empirical studies, a guided inquiry-based instructional approach was chosen as the instructional approach for the intervention.

1.7. Definition of basic terms

Attitude: refers to pre-service physics teachers' preference for physics laboratory experiments in the laboratory course that incorporated the concepts of electricity and magnetism

Blended experimentation: refer to the combination of both virtual and real experiments in the context of every experiment in a way that meets the requirements of each experiment alone.

Conceptual understanding: refers to students' understanding of electricity and magnetism concepts, which enables them to answer questions and solve problems on standardized tests.

Conventional laboratory: refers to the traditional table top and hands-on experiments where students are expected to follow instructions to gather data according to specified methods and write up reports.

Guided Inquiry-based learning (GIBL): refers to an instructional strategy in which pre-service physics teachers are given questions and are encouraged to follow certain steps on their own with the guidance of a physics teacher and laboratory technician to arrive at a solution.

Manipulative: - In the context of this study, manipulative refers to engagement or interacting with real or virtual components.

Physics Learning: - It refers to the dependent variables expected of pre-service physics teachers at the end of the intervention, namely conceptual understanding, understanding of the nature of science, and attitude toward physics laboratory.

Practical Skills: refers to learning by doing, which entails careful and step-by-step observation and investigation of a question or activity.

Preservice physics teachers: refers to students who are enrolled in CTEs in a three-year linear physics diploma program and who are required to successfully complete course work and a practicum in the final semester.

Real Experimentation: It refers to experimentation in the physics laboratory course using real or physical materials and equipment such as resisters, wires, ammeters, voltmeters, switches, and lamps.

Understanding of the nature of science: Refers to how closely pre-service physics teachers' nature of science (NOS) views, assumptions, and explanations align with scientific explanations.

Virtual Experimentation: Refers to mode of experimentation used in the physics laboratory course that makes use of PhET interactive simulations to construct virtual versions of the materials and equipment.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Introduction

The current study examined the effectiveness of blended mode of physics laboratory experimentation on learning outcomes, including conceptual understanding, understanding of the nature of science, and attitudes toward physics laboratory experiments on electricity and magnetism. In order to do this, a second-year linear diploma program physics laboratory course was selected as the intervention material, and guided inquiry-based learning was used as the instructional strategy for both the treatment and comparison groups. This chapter of the study attempts to review prior related research works, as these are the basics for framing the problem, methodology, and discussion sections of the research. The review focuses on philosophical and theoretical orientations, goals of science education in global and national contexts, physics education research in developed and developing countries, main focuses of physics education research, experimentation as one method of physics instruction, blended modes of physics experimentation including solely real and virtual experimentations, inquiry-based learning approaches, a summary of the literature review, research gaps, and conceptual framework of the study. Besides, the review focuses on pre-service physics teachers' required learning outcomes, such as conceptual understanding, understanding of the nature of science, and attitude towards physics laboratories.

2.1. Science education

Science plays significant roles in the development of any country in all respects, such as economic, political, social, and cultural concerns. Science education serves as a vehicle to promote investment and boost innovation and technological performance. As a result, countries set goals and deploy enormous resources in scientific education to promote science and technology in order to support and sustain economic growth and then become leaders in science, innovation, and technology (Kola, 2013; Olagunju, et al., 2003). Despite advancements in science and technology, the world today is burdened with contemporary challenges such as climate change, insufficient energy resources, pandemic outbreaks, and political instability, all of which require multifaceted countermeasures. There must be readiness in all aspects to respond to contemporary challenges accordingly. As a result, the teaching and learning processes in science education must keep up with technological advances and societal expectations, and schools at all levels must adapt to the sociocultural and economic demands of students as well as society at large.

To achieve that aim, science can be effectively taught through constructivist strategies, in which learning is a process in which the learner actively participates and develops new concepts. Many innovative science teaching strategies have been devised by different scholars and educators and have been shown to have a significant effect on the students' academic achievement when implemented appropriately. Inquiry-based learning is one of these ways in which the teacher plays the role of a facilitator and guide in the learning process while the student takes the initiative and becomes active in the construction of knowledge. In learner-centered science classrooms, students take the lead in the learning process, becoming researchers in the design of experiments, hypothesis testing, and drawing conclusions (Sreedevi & Sudhir, 2011; Tytler et al., 2003). According to authors who reviewed research articles, guided inquiry instructional models enhanced conceptual understanding, experience, attitude, and students' achievement more than conventional instructional approaches (Berie et al., 2022). Although there are efforts, the authors noted that inquiry-based learning has not yet become a common teaching and learning strategy in Ethiopian science education. There have been numerous revisions that have changed the science curricula in various nations to conform to the inquiry-based approach. For instance, *A Framework for K –12 Science Education* (NRC, 2012) was developed as a means of responding to the decline in science education and key socio-political events (Pringle, 2020). This framework suggested a number of instructional strategies for K–12 classrooms, including questioning, conducting investigations, gathering and analyzing data, developing explanations, and communicating information, among others (NRC, 2012, p. 49).

In a similar fashion, the curriculum framework (KG –Grade 12) for Ethiopian education was developed to be flexible to changing global conditions (MOE, 2009). The curriculum framework contends that the world is changing at a constant rate in all aspects, and that the fast and globalized world we live in necessitates new knowledge, values, skills, and attitudes on the part of the individual. It adopts active learning concepts to education as the best responsive means of achieving the required changes. The framework recognizes learners' active participation in the learning process through participation, production, and contribution. Additionally, it emphasizes on essential active learning terms like watching, doing, and debating.

Teachers at all levels must be prepared to meet the learners’ and society's demands in compliance with the reforms. Developing a framework document would not be an end in itself; rather, it requires all stakeholders to collaborate to ensure genuine implementation. To improve students' meaningful learning, curriculum, instruction, and evaluation must be adequately integrated into the framework (NRC, 2012; MOE, 2009). Teachers must be well educated, as well as get orientation and training on new teaching approaches, in order to implement the strategies. Pre-service science teachers, in particular, will require experiences that will assist them in understanding how students think, what they are able to accomplish, and what they might fairly be expected to perform under supportive teaching settings. They also require opportunities to learn how to prepare, organize, and manage resources; apply safety measures; form student groups; and assist students as they gather, represent, analyze, and interpret data; discuss data; argue from evidence; and draw conclusions (NRC, 2012).

Studies have shown that pre-service teachers have limited chances to participate in inquiry-based learning, and developing classroom environments that foster the growth of students' thinking abilities is likely to be even more difficult for them (Tanak, 2020; NRC, 2012). In science teaching, teachers have a unique opportunity to foster students' inherent curiosity about the wonderful natural world, experience and examine interesting objects and events, study relevant theoretical ideas, and progress in scientific understanding. Science laboratory experiments in general are one-of-a-kind resources that may boost students' enthusiasm for science, their understanding of science concepts and methods, their knowledge of crucial instruments, and their abilities that can help them acquire new understanding (Lunetta et al., 2007). Laboratory experiments and activities provide significant contributions to the aforementioned benefits. Thus, prospective science teachers must be well educated and trained in science laboratory experiments and activities in order to arouse students' interest.

Scholars claimed that advances in technology and globalization have brought extraordinary speedy economic development to the world since the late 20th century and the launch of the 21st century (Liu, 2009). It is further argued that the period mentioned was more peculiar in determining a nation's economic development than ever before by creating a demand for a scientifically literate populace and technical workers. It seems that because of these dramatic changes, a renewed call for reform in science education has emerged in developed countries like the US and many other countries. Because of contemporary challenges such as climate change, depletion of natural resources, growing poverty, and political crises, the significance of science is likely to be more influential on the future of society than ever before (Kaptan & Timurlenk, 2012). Cognizant of this fact, nations around the world, developed and developing, are struggling to establish quality science education in their education systems. Despite the efforts made, there are many problems and challenges to quality science education both in developed and developing countries, even though there are differences (Kaptan & Timurlenk, 2012; Yoldere & Adamu, 2014).

It has been pointed out many times that present conditions in science classrooms are making it difficult to meet 21st century science education standards (Glaze, 2018; Baloyi, 2017). To alleviate and reverse the problem, emphasis needs to be given to science teacher preparation. Teachers need to help their students become 21st - century intellectuals. Students must not only learn fundamental science concepts and principles, but they must also develop critical thinking and problem-solving abilities through inquiry teaching. Emphasis should be placed on several components of teacher preparation, such as knowledge, skills, attitude, and values. Researchers noted that teacher preparation programs can influence pre-service teachers' views about science teaching and inquiry-based learning (Lunetta et al., 2007).

Evidence has revealed that conventional science instruction has been revealed to be ineffective in changing students' understanding of concepts and meanings of the physical world, even after many years of repeated reforms. Conventional science instruction has been demonstrated to be ineffective in changing students' understanding of physical world concepts and meanings, even after taking an advanced yet conventional course (Eshetu & Alemu, 2018; Hake, 2007). This necessitates the use of reformed instructional methods such as interactive engagements, which assist students in actively participating in their learning and understanding of physical concepts and phenomena. According to Osborne (2017), science education should place a strong emphasis on the need to develop deeper conceptual understanding, genuine knowledge in the light of its context of use, connected and coherent knowledge, and teamwork. The preferred method of teaching and learning science is to help students actively participate in the content, rethink laboratory structures, and use engaging and active involvement to address misconceptions about science and scientists (Glaze, 2018).

In Ethiopia, the new education and training policy identifies that entirely expository styles of teaching and assessment strategies that emphasize pure recall of factual information may lead to poor citizenship development (Bekalo & Welford, 2000). According to the authors, the goal of the new education and training policy for science education was to develop a curriculum and instructional methods that would actively advance students' conceptual and procedural understanding through the close integration of theory and practice. Science education research findings revealed a number of remedies to strengthen science education, of which practical work is one distinctive feature. Scholars claim that practical work is crucial to improving student attitudes towards science and for the later study of advanced science courses such as engineering and medicine (Kaptan & Timurlenk, 2012; Hurd, 2000).

Many developing countries in Africa, including Ethiopia, have given due emphasis to science education, realizing its role in the overall development of the nation (Tyokumber, 2010; Yoldere & Adamu, 2014). The economic challenges on the one hand and the regressive scientific and technological advancement on the other hand are the major challenges of science education in developing countries. In addition, poor literacy rates, very poor investment in human and domestic capital, and other crises hinder the quality of science education in developing countries. When it comes to classroom science instruction, it needs qualified science teachers, reformed instructional strategies that promote active engagement of students in their learning, appropriate assessment techniques that could be supported by technology, and up-to-date laboratory equipment and facilities. These issues are also the challenges of science education in Ethiopia (Teferra et al., 2018; Dessie, 2015). Innovative instructional strategies, such as an inquiry-based approach, are suggested in order to advance the quality of science education.

2.2. Physics education

A large body of science education studies has shown that conventional teaching and learning strategies are ineffective for providing quality science education. In particular, students' understanding of many physics concepts through conventional instructional methods lacked solid conceptual understanding (Volkwyn, 2020; Fan, 2015; Finkelstein, 2005). The conventional instructional methods resulted in students having little conceptual understanding of physics (Eshetu & Alemu, 2018), misconceptions (Cahyadi, 2004), rote learning, and mere mathematical problem solving. The physics education research (PER) community has attempted to identify and theorize students' learning of physics concepts as well as investigate challenges associated with conceptual knowledge acquisition (Fan, 2015). PER has examined a wide range of topics, including conceptual understanding, problem solving, epistemology, attitudes, assessment of specific instructional interventions, technology, social aspects, and instructional materials (Beichner, 2009). Additionally, one of the major themes of PER is practical work and laboratory experiments (Vilaythong, 2011; Sassi & Vicentini, 2008).

Physics is a hands-on and mind-on inquiry-based discipline by nature (Vilaythong, 2011). It is an experimental science that strives to observe, characterize, model, and comprehend the natural world in which we live (Sassi & Vicentini, 2008). Practical work, laboratory experiments, and other activities therefore play a central and distinctive role in physics education (Vilaythong, 2011; Hofstein & Lunetta, 2004). Because of their significant benefits to learning, practical work and laboratory experiments have been given a crucial and distinct place in physics education (Baloyi, 2017; Hofstein & Lunetta, 2004). These authors claimed that for many students, practical work and laboratory experiments consist mostly of manipulating equipment rather than manipulating concepts. Although it is widely accepted that laboratory experiments are essential to the teaching and understanding of physics, the majority of school physics teachers lack the skills necessary to organize and carry out effective laboratory instruction (Vilaythong, 2011). For instance, many present laboratory courses continue to be thought of as a place for illustrating physics concepts and principles for the lecture course (Bao & Koenig, 2019; Meltzer & Otero, 2015).

Practical work, laboratory work, laboratory experiments, and activities are terms that are used vaguely and interchangeably. Many authors identified an experiment as a subset of laboratory work. Laboratory work is again a subset of practical work, which is the components of the physics education curriculum (Vilaythong, 2011). Many authors have stated that physics is a practical subject, and laboratory experimentation is one of the most important parts to physics education. Laboratory experimentation is an integral component of physics instruction (Akarsu, 2010; Duit & Tesch, 2010; Koponen & Mäntylä, 2006). There is dispute concerning the importance of experiments in physics instruction, despite the fact that many authors believe that experiments are important for enhancing physics learning (Abrahams et al., 2013; Lunetta et al., 2007; Koponen & Mäntylä, 2006; Millar, 2004). For example, Koponen and Mäntylä (2006) noted that the literature has a variety of views on the role and purpose of experiments that range from experiments functioning for verification purposes to experiments refuting theories. It serves as a helpful reminder that how we view physics experiments is important, and that how experiments are done affects their outcomes.

The reformed physics instruction views experimentation as a process where students are encouraged and guided to construct their own meanings and knowledge (Trumper, 2003; Etkina et al., 2002). These ideas have their roots in constructivist theories of learning. Though different authors focus on the educational goals of experimentation in various ways, Koponen and Mäntylä (2006) mentioned that experimentation provides an opportunity to participate in the acquisition and construction of knowledge. Additionally, it offers the chance to learn how the meanings of physics concepts and laws are generated and how that knowledge is obtained and supported. Apart from personal experiences in constructing knowledge, students' social interaction has a vital role in expressing their ideas, making reflections on their own learning, and making explicit their own reasoning. The notions mentioned above demand a social constructivist theory of learning, which is why they were selected as one of the theoretical perspectives used to guide the study.

Even though the knowledge of physics is applied in many areas, delivering quality physics education is laden with many challenges. According to NAE (2010), shortage of physics teachers, content overload, changing the philosophy of classroom instruction, poor assessment techniques, and inadequacy of instructional materials and facilities are major challenges to Ethiopian physics education. Physics education in Ethiopia is not an exception in that it is full of many problems and challenges in order to maintain its quality. For instance, studies on physics education in the Ethiopian education system (Worku & Alemu, 2021; Eshetu & Alemu, 2018; Dega et al., 2013; Kassa & Damtie, 2007) and overseas (Li & Singh, 2016; Meltzer & Thornton, 2012) reported low students' performance. These and other similar studies have demonstrated that conventional physics instruction is unproductive for teaching different physics concepts. For example, the study by Worku & Alemu (2021) on teacher-student interaction indicated that teachers' attempts to advance students' grasp of physics concepts within the observed classroom culture appeared to be inadequate. The authors went on to say that the interaction between the teacher and students was characterized by the utilization of low-level questions, inefficient teacher support and intervention, an unfavorable classroom environment for dialogic engagement, and concentration on descriptions and definitions of terminology in the curriculum.

Interactive engagement strategies are recommended to help students understand conceptually challenging courses substantially above what is achieved by conventional approaches and help for longer retention (Volkwyn, 2020; Meltzer & Thornton, 2012). Though many other studies in physics education have reported that interactive engagement and other improved modes of instruction are effective in developing a sound conceptual grasp of physics learning, this will not be true per se unless physics teachers are educated in a way to successfully implement the curriculum as a whole. That is why Hake (2007) claimed that the development of improved instructional strategies for enhancing student learning in physics is unlikely to be fruitful unless teachers are educated to use those strategies effectively.

Experiments play many roles in physics, such as testing theories, pointing out new theories, providing hints toward a mathematical model of a theory, and providing proof for the existence of the entities involved in the theories (Etkina et al., 2002). Because of its nature, experimentation is crucial for physics teaching and learning since it provides opportunities to exercise students' curiosity (Faour & Ayoubi, 2018). When it is implemented in the form of reformed instruction, experimentation in laboratory activities becomes an integral part of the physics curriculum from pre-K to 16 (NSTA, 2007). Laboratory experiments and activities have been shown to help students acquire ideas about the nature of science (Lunetta et al., 2007), improve practical skills and understanding of theory (Hanif et al., 2009), boost students' interest in physics, develop a deeper understanding of physics concepts and procedures (Vilaythong, 2011), and capture the spirit of inquiry (Otero & Meltzer, 2016).

In order to realize the goals of experimentation in physics, physics teachers should be educated appropriately to improve their understanding of science concepts, demonstrations, and experimentation skills. Though science teachers in general favor experimental activities in science, they fail to possess some of the science process skills, such as conducting laboratory experiments (Akarsu, 2010). Despite the fact that experiments are considered essential to effective physics instruction, many physics teachers lack the necessary knowledge and skills to plan and carry out efficient laboratory instruction (Vilaythong, 2011; Sweeney & Paradis, 2004). Sweeney and Paradis (2004) indicated from their research that exposing pre-service physics teachers to science education research activities would result in the formation of a network of qualified teachers. This, in turn, can be anticipated with the mobilization of a critical mass of physics teachers, with important implications for scientific inquiry quality and science culture.

The educational objectives, abilities, and experiences of the teachers, as well as the students' views of their learning, can all influence the quality of laboratory work (Millar et al., 2002). The authors stated that when laboratory experiments are conducted, what the students actually perform on the task at hand and what they actually achieve can be observed. These actions and learning outcomes will be affected by the students' attitudes toward science and learning as well as by their practical and institutional environments. Teachers at various levels, including university, college, and high school teachers, claimed that laboratory activities would help students gain a better understanding of physical concepts and processes. Scholars did, however, acknowledge that there were numerous issues with laboratory work organization (Vilaythong, 2011). These variables, including economic, personal, cultural, educational, administrative, curricular, and study culture variables, have all been identified as contributing to the lack of practical work in physics education. Many of the challenges will be resolved if physics teachers are well educated and devoted. Hence, in order to assist their students in conducting physics experiments, physics teachers need to have adequate training in the experimentation process.

The challenges related to Ethiopian physics education can be addressed at best by well-educated pre-service physics teachers, since the teacher, among other factors, is the critical element for quality education (Darling-Hammond, 1995). The physics teacher should be educated in order to move with the dynamism of the world so that up-to-date research findings regarding instructional strategies, learning theories, and assessment techniques will be properly employed. For example, abundant literature in the area of PER suggests that conventional instruction where there is passive lecture, recipe-type laboratories, and mere algorithmic problem solving fails to enhance conceptual understanding of concepts in physics, whereas interactive engagement methods such as inquiry-based teaching (McDermott & Redish, 1999), peer instruction (Lasry et al., 2008), and activity-based teaching enhance learning in physics (Hake, 2007).

Physics laboratory courses can be divided into three basic categories: concept laboratory, skill laboratory, and process laboratory (Sokołowska & Michelini, 2018). Concept laboratories assist students in understanding physics phenomena and concepts; skill laboratories enable students to build practical scientific skills, including handling equipment and working properly, and process laboratories help students solve a research question using their skills, concepts, and cognitive processes. The objectives of the particular physics laboratory course will determine the type of laboratory that will be used in that course. Other scholars listed various main goals of laboratory teaching, such as promoting conceptual understanding, boosting attitudes towards the laboratory, and enhancing understanding of the nature of science (Lunetta et al., 2007; Hofstein, 2017). The authors stated that some variables that need to be considered include the equipment and materials available for use in the laboratory experiment, student-student and teacher-student interactions, the nature of activities, the teacher's guidance, and the laboratory material.

2.3. Areas of physics education research

Physics education research (PER) is concerned with understanding how students learn physics at all levels and developing techniques to assist students with varying prior preparations in learning physics more efficiently (Singh, 2014). According to Akarsu (2010), PER is not limited to investigating and studying physics content understanding and curriculum design. PER also focuses on enhancing students' conceptual understandings of physics concepts using a variety of science teaching methods, including constructivism, active learning, and the inquiry approach, all of which have been developed specifically for science education. Physics education experts are engaged in a variety of research topics, including concept learning, student misconceptions, conceptual difficulties, physics epistemology, technology components, instructional materials, and curriculum development. Many of the curricula and pedagogies that depend on PER are founded on the core study finding that conventional teaching focused on telling is ineffective for assisting students in learning physics. Students need to develop their own understanding; however, the teacher plays an important role in assisting students in doing so (Bao & Koenig, 2019; Singh, 2014; Akarsu, 2010).

In a study by Bao & Koenig (2019) on PER for twenty-first century learning, it was noted that it is unwise to blindly follow trends in education technology and commercially motivated initiatives, as appealing as these may seem, before such treatments have been demonstrated to be beneficial by study. The authors emphasized that while trends come and go, educators take into account young children, who have a limited window of opportunity to experience education. The educational goals for physics are shifting in favor of ability-fostering learning as well as extending and integrating with other STEM subjects. This implies that our emphasis should vary depending on the circumstances and challenges we confront. Furthermore, we should not use initiatives that have arisen as a result of technological improvements without ensuring their success through interventions. In this aspect, it is true that PER focus can change over time. Furthermore, it is critical to investigate innovative teaching approaches and strategies proposed by scholars before implementing them on a large-scale in the education system. Similarly, different physics laboratory learning environments must be investigated before being implemented in large scale classrooms.

2.4. Practical works in physics education

Historically, science education reforms in the 1960s were aimed at helping learners experience and understand science and practice the skills that scientists use to understand and explain phenomena and processes in the natural world (Yager, 2000). During this time, inquiry-based learning was regarded as the major focus of teaching science, though it was not implemented as planned. From a historical point of view, inquiry-based learning was developed in response to conventional practices of instruction where students were required to learn by rote and memorize information received from the teacher and instructional materials. It was rooted in constructivist learning theories, which in turn derived from constructivist philosophy (Walker & Shore, 2015; Duffy & Raymer, 2010). Some authors believed that inquiry-based learning and teaching were particularly grounded in social constructivism (Walker & Shore, 2015). That is why most science educators agree that inquiry laboratories, when appropriately designed, have the potential to improve students' conceptual understanding, constructive learning, and understanding of the nature of science (NOS) (Abd-El-Khalick et al., 2004; Hofstein & Lunetta, 2004). Besides, these types of laboratories help to enhance scientific concepts and processes, from problem formulation to drawing conclusions on scientific problems.

Many authors noted that the launch of Sputnik kicked off science initiatives in the 1960s and 1970s (Mbonyiryivuze et al., 2018; Meltzer & Otero, 2015). Science education reforms taken place before the launch of Sputnik were focused on a series of prearranged laboratory experiments, a text, a syllabus, and a series of standard problems for schools and colleges (Mbonyiryivuze et al., 2018). However, following the launch of Sputnik, the nature of the science curriculum and the mode of science teaching and learning were evaluated in various countries, and several reforms were made (Meltzer & Otero, 2015). It can be said that Ethiopian science education was part of these reform initiatives because it has been impacted by outsiders. According to Melese & Tadege (2019) and Bishaw & Lasser (2012), Ethiopia's education system was impacted by the education systems of France, Italy, Britain, America, and other communist countries in order, from the beginning of modern education to the present day.

Education, roughly defined as a system of learning from textbooks and carried out in large classes, was a phenomenon with a strong colonial history in most African countries, notably Sub-Saharan Africa (Negash, 2006). Though Ethiopia was not colonized, the education system in place at the time was strikingly similar to that of other African countries that had been colonized for longer periods of time. Before the new Education and Training Policy was adopted, the education system was criticized due to various flaws, including ineffective teaching methods and a lack to incorporate essential practical experience (Bekalo & Welford, 2000). The authors extend that at all levels of education, the policy promotes problem-solving approaches to the teaching and learning process. Furthermore, the policy realizes that entirely expository approaches to teaching factual material to students in order to prepare them for examinations may not promote good citizenship.

One of the goals of science education should be to provide students with the necessary understanding of concepts and methods to help them understand the world around them (Hofstein, 2017; Bekalo & Welford, 2000). Practical work and laboratory experiments can help students gain the conceptual and procedural understanding needed both within and outside of the classroom. The authors noted that not only the new education and training policy but also legislation from past imperial and communist regimes had urged for science to be taught as a process of inquiry, at least in part. There were several issues with the implementation, and there were some confusions in the conceptualization of practical work. Many teachers believed that practical work necessitated complex and expensive imported equipment, materials, and apparatuses. There was a constraint on other practical activities (Bekalo & Welford, 2000). As a result, science as well as physics teachers must be aware of, educated about, and trained in the definition, what constitutes it, and how to employ practical activities appropriately. This is a critical issue in the current situation because there are different alternative laboratory activities available, including technology-enhanced laboratory manipulatives.

Though there are agreements on the substantial contributions of practical work and laboratory experiments in physics education, there are continuing debates regarding meanings and definitions, goals of practical work, epistemological roles, and assessment (Vilaythong, 2011). Laboratory work prepared for students can be defined as an intentionally selected learning environment where students participate in an intended learning experience so that they interact with materials and equipment to observe and understand various phenomena (Hegarty-Hazel, cited in Bradley, 2005). This definition of laboratory work does not embrace other forms of practical work, such as field visits, that can be used in the teaching and learning process outside the laboratory room. Other scholars consider laboratory experiments a learning experience in which students are provided with materials to observe and check various phenomena in the laboratory classroom (Vilaythong, 2011). Trumper (2003) referred laboratory work as activities based on tests, observations, and experiments investigations done by students. Others considered laboratory work a component of practical work that occurred in a setting that was specifically established so that students may participate in organized experiments and activities (Bradley, 2005). Some other authors explained laboratory experiments as learning experiences in which students engage with models, equipment, and materials to observe and understand natural world occurrences (Babalola et al., 2020; NRC, 2005; Hofstein & Lunetta, 2004). Others still regarded practical work as any type of teaching and learning that requires students to observe and interact with real materials and objects (Vilaythong, 2011). This notion, however, does not consider practical work originating from virtual materials into account.

In the Ethiopian context, the Education and Training Policy (TGE, Education and Training Policy of Ethiopia, 1994) advocates problem solving and practical approach in the teaching learning process. According to Bekalo & Welford (2000), practical work is defined as an activity that encourages students' active involvement in their own learning. It includes hands-on activity with equipment; individual work like measurement, observation, and investigation; many type of experiments that may be performed in the laboratory, classroom, or elsewhere. Besides, practical work includes a variety of other ways including teacher demonstration, group discussions of questions and their solutions, and interaction. The purpose of the definition seemed to encompass all activities that help students in the learning process.

Many scientists and science educators agree that practical work and laboratory experiments are an essential part of science education. However, there is lack of consensus and clarity regarding the pedagogical basis and the significance of educational objectives of laboratory experiments in science education (Musasia et al., 2016) In addition, the potential of laboratory experiments in science education has been contrasted with questions regarding its efficiency and benefits (Hofstein & Kind, 2012). Despite all these inconsistencies, many authors noted that laboratory experiments has an important role for the success of science education if it is used effectively (Hofstein, 2017; Lunetta et al., 2007; Hofstein & Lunetta, 2004).

However, for practical work and laboratory experiments to be effective as a learning resource, we must first identify what we want students to learn from each session and then consider the best way to achieve that goal. For many students, the physics laboratory experiment is primarily focused on manipulating equipment (doing) rather than manipulating ideas (thinking) (Hofstein & Lunetta, 2004). This should not be the case; rather, effective physics laboratory activities involve both hands-on activity and minds-on engagement. This is due to the fact that physics is a hands-on (doing) and minds-on (thinking) inquiry-based subject by its very nature (Vilaythong, 2011), and students may be more successfully hands-on and minds-on when they feel they grasp how the equipment and apparatus they are using work (Millar, 2004).

2.5. Learning theories and their implications for practical work in physics education

Research evidence revealed that scholars have been attempting to question and understand how people learn for over 2000 years. According to Darling-Hammond (1995), the dispute over learning theories has been going on at least since the time of the Greek philosophers, including Socrates, Plato, and Aristotle. These pioneering philosophers' conceptions of learning were at opposite ends. Socratic dialogue, Platonian rationalism, and Aristotelian empiricism were the core ideas of thought for these philosophers (Hammond et al., 2001). This debate gave rise to the present emergence of learning theories.

Learning theories claim about how people learn and draw implications for the aim of education, the curriculum, and the roles of the teacher and students. The inclusion of science as a formal academic discipline in school curricula started toward the end of the nineteenth century. The pioneers of science education made an effort to teach it in schools in the same way as other subjects. Curriculum, science educators became aware of developments in psychology. Educational psychologists in the 20th century developed learning theories that explained how children acquired skills and knowledge. These theories have had a profound impact on how science is taught. The three most well-known theories of learning are constructivism, cognitivism, and behaviorism. It would be helpful to understand the underpinnings of these three learning theories and consider how they impact science instruction.

Behaviorists focus on observable and measurable behaviors and define learning as the acquisition of new behaviors established by environmental conditions. The role of the teacher is focused largely on transmitting information to the learner, and the classroom interaction is concentrated on behavior modification (Agarkar, 2019). According to the proponents of behaviorism, science teaching could be linked to making children acquainted with scientific information without paying attention to the methods of science. From the onset, behaviorists emphasized objective measurements and believed that the results of laboratory experiments were not predetermined by an individual’s judgment or opinion. This implied that physics laboratory experiments were assumed to be theory-free, which was criticized by many authors.

In order to restore equilibrium between the internal and external worlds, Piaget argued that individuals generate sensory data that may either be assimilated into preexisting schemas or altered to accommodate newly acquired information (Millar, 2004). As a result, practical work is very important for understanding phenomena in the world. That is, the learners construct their own representations of the external world through action on it, though this notion was criticized because of the denial of interpersonal interactions. According to cognitive theory proponents, instruction will be effective if it is based on the students' existing schemas and mental structures. That is, students' should be helped to connect the new information they learned with existing knowledge in order to say meaningful learning has taken place. Following this, different cognitive strategies such as analogies, metaphors, concept mapping, and advance organizers were suggested for science education (Agarkar, 2019).

Social constructivists believe that knowledge is constructed through one's own private experiences and interactions with the external world. As a result, the learner actively participates in the construction of knowledge and the teacher facilitates this effort. In this view, learning is an enculturation process in which learners eventually internalize the skills and knowledge they develop through interacting with other people and with cultural resources (Kay, 2016). This notion has implications for the classroom learning of science. The teacher provides a wide-ranging framework, establishes a problem that needs to be investigated, and supplies resources so that students can build knowledge as they engage in real-world interactions. In this notion, the teacher has the role of facilitating students' learning and helping them engage in their own learning, though there are different levels of teacher involvement.

Data and ideas obtained from practical work in physics classes are therefore subject to social interaction, so that these ideas will be modified and refined through consolidation when they are in agreement with others and challenged when contrasted with others (Millar, 2004). According to social constructivist ideas, students have to be equipped with the necessary apparatus and materials to solve authentic problems in order to gain practical skills and knowledge of phenomena in the external world (Yang & Heh, 2007). In this notion, the learning process is a social activity in which social interaction is essential for developing cognition, which again leads to new ways of constructing ideas together.

2.6. Different modes of physics laboratory experimentation

Many reformers of physics education and curriculum designers have frequently drawn arguments for their notions from constructivist theories of learning (Niaz et al., 2003; Trumper, 2003). However, researchers disagree about the role of experiments to science education (Koponen & Mäntylä, 2006). It has been revealed, for example, that an extensive practical work had little effect on students' understanding of concepts (Watson et al., 1995). The author justified that this may be due in part to the lack of discussion of explanatory models that are connected to work. That is to say, the majority of students did not alter their explanations of the topic, concepts of gas combustion, using the knowledge they had learned through laboratory work. The recommendation was that students should spend more time engaging with ideas and less time working with equipment if practical practice is to have any significant impact on student theory reconstruction and linking of concepts in diverse ways. The efficacy of laboratory experiments toward the goal of acquiring scientific concepts is challenging and ambiguous to evaluate (Hodson, 1996). However, other authors claimed that the poor outcomes were caused by the method by which the experiments were carried out (Koponen & Mäntylä, 2006). This ineffectiveness could be attributed to experiments being utilized too easily for verification, the laboratory having a low cognitive demand, and experiments being used mostly to validate what has previously been taught (Trumper, 2003). In addition, oversimplified inductive use of experiments, which considers students as *novice researchers*, was determined to be an ineffective method (Niaz et al., 2003; Trumper, 2003). We can infer from earlier studies that the inclusion of practical work and laboratory experiments does not, by itself, result in effective learning; rather, the way the experiments are conducted matters, among other things.

However, there are debates regarding the role of experiments, ranging from their nature as verification to the construction of knowledge as informed by constructivist learning (Niaz et al., 2003; Trumper, 2003). That means, experimentation in physics education should get due emphasis in order to attain the contemporary goals of physics experiments in the laboratory. According to Koponen & Mäntylä (2006), the generative role of experiments, which helps to reduce the epistemological drawbacks of simple induction or narrowly focused verification application of experiments has been advocated. There is a general consensus that experiments are used for a multitude of reasons in physics instruction if they are appropriately implemented. Experimentations in physics can be done either in real, virtual or blended real with virtual modes. The characteristics of each modes of experimentation, the advantages and limitations of each mode of experimentation revealed by empirical research and limitations are discussed in section 2.7 by referring previous research works.

In the previous sections of the literature review, it was mentioned that practical work in physics curriculum encompasses laboratories and experiments. These aspects can be done in real experiments, virtual experiments, or by blending both real and virtual ones. Whatever the case, they need a budget and skilled manpower. Many authors ignore the availability of necessary facilities and skilled manpower when they recommend the virtual mode of physics laboratory experimentation over the real one. This is mainly a severe challenge for developing countries, where there are costly ICT services and a shortage of skilled manpower. The real laboratory materials and equipment need huge investment, which is a challenge for developing and developed countries, though the degree varies. Besides, students are using much of the equipment and materials that were in use in the past. This again needs improvement. Therefore, the future of laboratories needs to be questioned.

Moreover, a recent incidence wherein the COVID-19 epidemic forced nations all over the world to lock down classrooms at all levels, beginning kindergarten to higher education. Following this incident, there was a problem of equity in accessing education among marginalized groups of the community, such as students in remote and rural areas where there is no access to ICT infrastructure and services. Though there were attempts to continue education using different alternatives, science education was challenged in many aspects, particularly in developing countries like Ethiopia. It is clear that the real enjoyment of science is the link between theoretical knowledge and understanding by experiments in the laboratory. Physics is among the natural science subjects in which students need practical work in order to represent events and phenomena in the natural world in their mental structure. However, it was challenging to undertake such a teaching and learning process, particularly in developing countries where students stayed at home. Developed nations applied different alternatives, such as the mail-order laboratory, the home laboratory, the online laboratory, and the interactive simulation laboratory. Therefore, it is very important to make the purpose of laboratory experiments in physics instruction clear from the start. Then, physics teachers, educators, and physicists need to think about how to articulate contemporary and unconventional ways of achieving the experience. It should be good if we work on the culture of relating what students learn with physical world phenomena. Actually, it is difficult to represent all the concepts learned.

According to Millar (2004), practical work in science plays a substantial role in helping students make relations between the domain of events, observable properties, and objects and the domain of ideas. The author further claimed that since the content of science is the physical world, the teaching of science should encompass seeing, handling, and manipulating real objects and materials. However, at least two things challenge the author's argument. On the one hand, the declining resources in schools and universities frighten to reduce the amount of experiments used in physics courses in the years to come (Sneddon et al., 2009). In addition, Hanif et al. (2008) claimed that some authors in the area of science laboratory education began to raise questions about the efficacy of laboratory because of the heavy cost needed to establish laboratories for science education. The shortage of materials and equipment for physics laboratories could be highly devastating in developing countries. On the other hand, the constructivist learning approach does not specify the type of manipulative whether real or virtual (Triona & Klahr, 2003). It only emphasizes the extent of active engagement in the teaching and learning process. This notion, together with the contributions and opportunities brought by ICT to the education system, encourages educators to think about alternatives to physics laboratory education. The recent crisis in education during COVID-19 could also prompt us to think about alternative ways of doing physics practical work and laboratory experiments.

Many institutions noted that science teaching should support student understanding of concepts and application of scientific inquiry processes and knowledge, with the effect that students become competent problem solvers (Yager, 2000; NRC, 1996). To attain this goal, science educators attempt to improve science learning by integrating instructional strategies with technology. It is repeatedly reported that a lot of challenges decreased the effects of practical experiments, such as a shortage of equipment, inadequate class time for experiments, the expense of experiments, and safety concerns. Many studies have emphasized the necessity of integrating technology with inquiry-based learning environments that can provide students with a variety of benefits (Williams et al., 2017; Hakverdi-Can & Sonmez, 2012; Yang & Heh, 2007). To support experiments in science laboratories, this could be possible through suppling learning resources, sharing ideas, introducing offline and online simulations, among others.

Supply of laboratory materials and equipment for science education, finance, trained manpower, and other problems and challenges are issues that force us to think of alternatives. In addition, the development of ICT has made great strides in the science laboratory in terms of its importance in the education system. However, in light of the global impact of the COVID-19 pandemic in 2020, the education system was as vulnerable as any other sector, and efforts were being made to implement an online and virtual learning system rather than a face-to-face education system. The COVID-19 pandemic has disturbed the education system almost all over the world. It has forced most teaching to move off campus, and then students learn online at home. More specifically, the laboratory class, which is the cornerstone of science education, has been in trouble. Thus, the challenges faced regarding practical work and experiments in science laboratory demanded alternative ways of conducting laboratory experiments. As one of the prioritized science and mathematics subjects, we need to think about how practical work and laboratory experiments will be managed in physics in the future.

Accordingly, the following are some of the options for science and physics students who are challenged to gain face-to-face laboratory: The first alternative is the mail-order laboratory, in which science laboratory kits are assembled at the school or institution level and delivered directly to students to perform experiments at home. This method has the advantage of allowing students to gain laboratory experience without regard to time constraints. However, there would be economic considerations, health and safety concerns, mailing challenges, and other obstacles while conducting experiments. The second alternative is the home laboratory, in which a wide range of science (biology, chemistry, and physics) activities can be investigated using commonplace things. As a result, it is critical to assist science students in designing laboratory experiments utilizing equipment and materials that may be available locally and at home. This strategy offers several advantages, including cost savings and assisting students in connecting what they study to the world around them. However, performing laboratory experiments with materials and equipment readily available at home is difficult, and competent personnel who can assist students are required. The third option is the online laboratory, which emerged as a good opportunity with the advent of ICT and involves the use of virtual elements in place of real or physical materials, or a combination of both. It maintains a high level of interaction with other students as well as with the material to be learned. Many people, however, stated that this strategy deprives students of hands-on experience and that they require adequate ICT facilities and competence.

The central question is the future science laboratory. In general, during times of difficulty and crisis, it is critical to focus on how the education system should be maintained and how children can receive a quality education wherever they are. Beyond theory, science education requires experience and practice, so it is critical to give it in a high-quality and timely manner. On the one hand, there is the advancement of ICT, and on the other, the laboratory approach we are now utilizing has been in use for a long time, so we must work on alternate and timely approaches. Actually, there are advantages and disadvantages to the many options outlined above; therefore, teachers and curriculum designers must carefully develop and oversee the science laboratory experiments.

2.7. Empirical evidence of real physics laboratory experimentation

Physical objects and drawings were utilized by ancient civilizations all across the world to represent real-life problems. Evidence revealed that the first manipulatives were used in the late 1800s for mathematical concepts, and manipulatives have been used by teachers and students since the early 1900s. Many academics are actively researching the use of physical manipulatives in the classroom and how this technology can support the teacher in classroom instruction (D'angelo & Iliev, 2012). Physical manipulatives have different designations, such as real, concrete, or materials that actually involve sensory skills. Scholars like Olympiou and Zacharia (2010) have designated real experiments as physical manipulatives with real-world physical or concrete materials and apparatus. Physical manipulatives are real or concrete objects that give concrete representations that students can use to support their acquisition of abstract concepts in science and other subjects (Beckwith & Theocharous, 2010).

Many benefits of using real experiments were identified by researchers that make use of real equipment and materials, including the acquisition psychomotor skills, the realization implementing safety issues, and the application of sensory input for gathering data, which are often considered to be involved in doing authentic science (Zacharia & De Jong, 2014). Besides, real experiments in physics help in acquiring conceptual knowledge related to touch sensory input (Zacharia et al., 2012), reducing learners' cognitive load of working memory, which leads to more complex understanding (Zacharia & Olympiou, 2011), and predicting experimental errors

(Brinson, 2015). These types of manipulatives have also been shown to have an encouraging effect on students' problem-solving abilities and conceptual understanding (D'angelo & Iliev, 2012).

Direct contact with materials and equipment is advocated as a precondition for learning physics through experimentation. This means that doing physics experiments without involving students in the real manipulation of materials and equipment, like in the case of virtual manipulative experiments, may limit students' learning (Zacharia & Olympiou, 2011). According to the authors, physicality is considered to be one special advantage of physical manipulatives. It serves as the foundation for learning and conscious memory as well as giving students the opportunity to directly experience scientific phenomena through experimenting with concrete objects (Gire et al., 2010). However, other scholars argue that it is manipulation rather than physicality that may be vital for learning through experimenting (Klahr, et al., 2007; Triona & Klahr, 2003).

According to Triona & Klahr (2003), if the physicality of materials boosts instructional effectiveness, then virtual manipulatives would be less beneficial than real ones. That is, none of the current major learning theories, particularly constructivist and cognitive learning theories, support the argument that physicality is required for learning (Zacharia & Olympiou, 2011; Triona & Klahr, 2003). In this regard, constructivist learning theory emphasizes the role of learners taking an active part in the learning process, whereas cognitive learning theory emphasizes the necessity for learners to actively engage with information and acquire a desired skill without requiring physical manipulation (Zacharia et al., 2012; Zacharia & Olympiou, 2011; Zacharia & Constantinou, 2008). Some authors argued and reported paradoxical findings, such as Zacharia et al. (2012). The authors investigated whether physicality is required for science experimentation in kindergarten. They found that kindergarteners who were given proper prior knowledge of physical manipulatives learned more than those who were given incorrect prior knowledge of virtual manipulatives. In other publications, these authors argued against the concept of physicality (Zacharia & Olympiou, 2011; Zacharia & Constantinou, 2008).

Learning theorists provide extensive theoretical support for the use of physical manipulatives. For example, learning theorists such as Piaget and Brunner assert that using concrete manipulatives is an important stage in the development of new concepts for learners. Furthermore, authentic interactions with their environment are thought to benefit learners. Real manipulatives can also be used to develop motor skills or to understand abstractions, as well as to promote hands-on engagement with the topic under study (D'angelo & Iliev, 2012). By experimenting with tangible materials as well as constructing physical objects, these manipulatives give students a hands-on opportunity to experience scientific phenomena (Gire et al., 2010).

2. 8. Empirical evidence of virtual physics laboratory experimentation

Globalization makes it easier for people to obtain and share the most recent knowledge by using technology. Technology has advanced significantly as a result of globalization in many sectors, including education. Along with the ways in which people live and work, media and technology have also had a profound impact on education. As information technology has advanced and the internet has grown in popularity, educators have begun incorporating media resources to boost learning outcomes. The development of technology, the expansion of the Internet's usage, and its availability in classrooms and homes around the globe have contributed to new types of educational instruction. Over the past decades, educational researchers and teachers have started to utilize interactive tools for teaching science and mathematics (D'angelo & Iliev, 2012). These are virtual manipulatives, or digital items that can be built into learning environments or utilized as stand-alone tools to support learning, such as conceptual understanding. Also, virtual manipulatives are virtual materials and equipment that exist in a virtual setting, such as simulations to laboratory experimentation (Zacharia & Olympiou, 2011). These types of experiments are provided via computer interface to learners to provide intuitive visual or auditory sensory activities (Li, 2015). The virtual simulation of a phenomenon or an event is designed to represent a realistic environment, and the computer provides the means to communicate with the learners.

Many advantages have been identified as benefits of virtual laboratories, such as simplifying reality by taking out details (Bell & Trundle, 2008), altering model features as the time scale changes, adding special features of reality such as simulation of current flow in an electric circuit, and adapting reality to serve the learning process (Zacharia & De Jong, 2014). A doctoral research study examined how first-year college students' success in conventional, hands-on laboratory experiments and virtual forms of investigations was influenced by prior science achievement (Marino, 2018). According to the findings, virtual laboratories were higher than hands-on laboratories for high achievers, while there was no difference for low achievers. According to the results, the authors conclude that using virtual laboratories does not negatively affect students' science achievements and may even help save resources, although it may widen the achievement gap between low-achieving and high-achieving students in the laboratory.

A study was conducted by Evangelou and Kotsis (2018) to investigate the effect of virtual versus real physics experiments on primary school students about the concept of frictional force. The findings revealed that if time is limited, students participated in a virtual experiment with less messy data gathering may be more beneficial than a real experiment. The authors noted that virtual experiments on frictional force are not less beneficial than real experiments, as evidenced by a comparison of the learning outcomes of students in the comparison and treatment groups.

A study by Sullivan et al. (2017) used a quasi-experimental design to examine how eighth grade students learned physics concepts related to work and the mechanical advantage of pulleys based on the sequence in which they participated in physical and virtual experiments. The results showed that there was no conclusive evidence of sequence, but that students who were taught using virtual experiments understood the concepts of work and mechanical advantage more effectively than those who were taught using physical ones. The conclusion that virtual experiments do not contribute more to the acquisition of conceptual understanding than real experiments is clearly refuted by these results. Further research is required to incorporate additional essential aspects regarding the use and manipulation of either virtual or real experiments while teaching physics concepts and phenomena to elementary school students (Evangelou & Kotsis, 2018; Sullivanet al., 2017), high school students (Ambusaidi et al., 2018), pre-service physics teachers (Marshall & Young, 2006), and undergraduate students (Aşıksoy & Islek, 2017; Tekbıyık & Ercan, 2015).

A study on pre-service teachers' use of virtual and improvised experimentation in science instruction was conducted in Zimbabwe (Bhukuvhani et al., 2010). It was a descriptive survey with a 20-item questionnaire to examine pre-service teachers' perspectives. The findings revealed that, despite their understanding of the benefits of virtual experimentation in science education, many of them did not use technology in their classrooms. It was suggested that African countries continue to implement ICT policies to support growth in a variety of socioeconomic sectors, including education, and to help guide development and competition. A study was conducted at Nigerian universities to develop interactive virtual laboratory simulation software for basic physics experiments. According to the results, virtual laboratory software was as effective as real physics laboratory experiments. However, the author claimed that virtual simulations have a disadvantage if students do not have real-world experience (Akpan et al., 2016).

2.9. Empirical evidence of blended physics laboratory experimentation

The phrase blended learning originally appeared as a new approach to teaching methods and learning styles around the beginning of the twenty-first century (Voa et al., 2017). Due to the constraints of the classroom setting in terms of promoting interaction, context, and reinforcement, blended learning was initially characterized by the training institution as a combination of online and in-person learning (Masie, 2006). Ashraf et al. (2021) and Graham (2006) elaborate on blended learning as a combination of face-to-face instruction that allows for more reflective and interactive knowledge construction. According to Köse (2010), blended learning is a learning strategy that incorporates a variety of pedagogical approaches and technological tools, and the nature of this strategy strongly relies on the objectives of instructional design. The above-mentioned definitions of blended learning are connected to its historical background. These either have something to do with integrating various instructional methodologies or combining online and traditional face-to-face instruction. The definition of blended learning used in this study is associated with physics classroom experiments.

With the emergence of the digital age, conventional teaching and e-learning, such as online learning, have been revised and progressively replaced by blended learning, which is an amalgamation of face-to-face and online learning (Le & Pham, 2021; Lin & Chiang, 2016). The teacher could teach some initial sessions in the classroom, and then students could move on to online interaction and learning in blended mode. Other authors defined blended learning as a formal or non-formal education program that incorporates online digital media into conventional classroom methods. It encompasses all teaching models that incorporate technology and streaming media, such as e-mails, learning management systems, social media, mobile technology and internet technology, and can be integrated with conventional methods of teaching (Deliktas & Stojkovska, 2019).

Changes in the educational system, along with new modifications put in place in response to these changes, provide reasonable grounds for identifying novel approaches and teaching methods to prepare teachers to solve a wide range of problems (Krasnova & Shurygin, 2019). The use of a blended instructional approach has been shown to be an effective way to give pre-service teachers the chance to learn in both online and face-to-face settings (Le & Pham, 2021). A quantitative survey was conducted to determine pre-service teachers' opinions of the implementation of blended approach on a science education methods course. The findings revealed that pre-service teachers had positive perceptions of blended approach in their course, but that some technical issues with the blended approach had a negative impact on their learning (Yılmaz & Malone, 2020). When using blended learning, a variety of pedagogical approaches are available, including student-centered, problem-based, the flipped classroom, inquiry-based learning, active learning (Deliktas & Stojkovska, 2019). Other studies have found that blended learning does not produce fully satisfactory results in millennials, and their satisfaction level with learning is lower (Dziuban et al., 2005).

There are different models of blended learning. The important thing is how to combine the advantages of conventional face-to-face teaching with technology-enhanced teaching methods. Teachers could add specific components to enhance didactic teaching, which prioritizes teacher-centered lectures rather than fully implementing computer-assisted teaching techniques in the classroom. When the state of the literature is considered, a blended learning approach combines conventional teaching with an e-learning system. The blended learning approach was also found to be effective in improving students' academic achievement scores, enhancing students' attitudes, and helping students spend more time on their learning task of mathematics as compared to face-to-face traditional instruction (Lin & Chiang, 2016).

Despite all its limitations, several studies have shown that ICT supports education systems in offering high-quality education in accordance with modern learning perspectives such as constructivism (Fu, 2013; Mikre, 2011). Teachers now have a number of valuable instruments for improving the teaching-learning process because of the advancement of modern technology, particularly the internet. In a number of school settings, these techniques have proven to be effective and beneficial (Shurygin & Sabirova, 2017). Encourage self-directed and student-centered learning, produce a conducive learning environment, enhance cooperative learning in a distance-learning environment, provide more opportunities to build higher-order thinking skills, enhance teaching and learning quality, and support teaching by fostering access to the course content are some of the advantages of using ICT in education. A critical review of the available literature on ICT in education revealed that ICT integration is a mediational process rather than a finished product. To accomplish successful technological integration, teachers, students, and school administrators should collaborate after investigating their points of view (Fu, 2013).

However, many questions remain unanswered in current research on technology-enhanced learning. For example, addressing student diversity in prior knowledge and learning styles necessitates an appropriate instructional strategy, as integrating blended learning does not suffice (Puente, 2015). A review of previous studies on blended learning was conducted, and the results were divided into those that improved student achievement, those that improved positive attitudes and engagement with blended learning, and those that had no significant impact on student achievement (Alsalhi et al., 2021). Conventional teaching, according to some teachers, is more effective in providing students with the required knowledge, whereas blended learning is difficult to manage (Ashraf et al., 2021). At the present time, it is important to determine one type of technology-enhanced learning, namely blended physics experimentation, which is a combination of real and offline virtual manipulatives of physics concepts. Blended learning uses the affordances of both real and virtual manipulatives, and it is suggested that this mode of experimentation is more advantageous than using the other two alone. This combination should take into account the advantages of each form of learning. With the advancement of ICT, blended learning can be used by combining real and virtual manipulatives at all levels of education, like primary school, secondary school, college, and university. The advantages of each form of experimentation were combined to establish the basis for blended learning (Shaidullin et al., 2014). Thus, blended modes of physics experimentation are among the contemporary educational technologies that are built on the concept of combining real and virtual manipulatives using a guided inquiry-based approach to instruction.

According to Shurygin & Sabirova (2017) and Shaidullin et al. (2014), blended learning models may include elements of self-education, interactive engagement mediated by computer technologies and electronic information, and the conventional interaction between participants of educational process. Scholars also recommend the following blended learning models: rotation model, face-to-face, driver model, self-blend model, flex model, online driver model, and online laboratory model (Shaidullin et al., 2014). These definitions of blended learning refer to the combination of e-learning and face-to-face modes. Blended can also be defined as a combination of virtual and real laboratory experiments in physics laboratory classes. As a result, Watson (2008) noted that different people have varied conceptions of blended learning. The author then listed a few of them as follows: integration of online and face-to-face learning, a course that integrates online and face-to-face instruction, and combination of different approaches to learning, such as blending virtual and real learning laboratory environments.

It can also be considered a program that combines conventional classroom instruction with digital media. There are many distinct pedagogical strategies available within blended learning, such as student-centered learning, problem-based learning, and the flipped classroom (Deliktas & Stojkovska, 2019). As it gives pre-service teachers the opportunity to work in both online and face-to-face settings, it gains popularity in teacher education programs (Le & Pham, 2021). Highly educated and equipped teachers can enhance their teaching strategies and learning environments to meet the needs of their students by adopting constructivist learning approaches (Abdullah & Hendon, 2016). The blended learning model lacks its own pedagogy; however, social learning theories, such as social constructivism, engagement theory, situated cognition, cognitive flexibility theory, variation theory, and as well as the harmony from these, strongly support it (Thomas, 2010). As a result, the foundation of blended learning is the provision of flexibility, enhanced interactions, and ongoing opportunities for learning outside of the classroom, and the ability to deal with a range of instructional resources in multiple formats, among other benefits. In short, blended learning promotes dialogue, student engagement, collaborative activities, online learning opportunities, and effective follow-up and assessment schemes. This is reasonably beneficial because conventional teaching methods generally lack student engagement and offer few opportunities for students to reflect on content.

Relatively new as a mode of teaching, scholars still perceive and define blended approaches in a variety of ways. Some authors refer to blended learning as connecting face-to-face teaching and learning with ICT (Li & Tang, 2017; Hinkhouse, 2013; Vesisenaho et al., 2010). According to Li and Tang (2017), blended learning is based on a thoughtful combination of learning theories such as constructivism, cognitivism, and behaviorism. The process consists of five major components: live events, collaboration, online content, reference materials, and assessment. Different people have different opinions about blended learning. According to Watson (2008), it can refer to almost any type of learning experience that includes some form of educational technology or a reasonable percentage of online and face-to-face curriculum and instruction strategy. Integration of face-to-face and online learning, a course that combines online and face-to-face delivery, and a combination of different approaches to learning achieved through the use of blended real and virtual resources are some of the various definitions of blended learning. In physics laboratory experiments, blended learning includes the combination of hands-on laboratories either with virtual or remote laboratories, which may be carried out using real experiments, a computer-based replica of the real laboratories, or the internet, respectively (Shaer et al., 2010).

This mode of learning can be applied to theoretical and practical courses. For experimental courses like physics, blended learning is a mode of experimentation that combines virtual experiments with hands-on or real experiments (Hamed & Aljanazrah, 2020). Scholars have identified the unique affordances of virtual and real experiments in physics education over using one of the modes of experimentation alone. That is why a number of scholars advocate the use of real experiments and virtual experiments in combination, in which part of an experiment or a series of experiments are conducted with real experiments and the remaining ones with virtual experiments (Olympiou & Zacharia, 2010). This mode of experimentation is termed as blended experimentation, and the reasoning behind it is that it combines the benefits of both real and virtual experiments. Regarding this, many researchers argue that since real and virtual experiments have their own unique affordances, it is through their combination that we can benefit in a learning environment (Olympiou & Zacharia, 2010; Winn et al., 2006). Regarding the results obtained through blended experimentation, it was reported that blended experiments or activities in any form of combination produced a better understanding of physical concepts than either real or virtual modes of experimentation alone, though the sequence in which the activities were presented matters (Atanas, 2018). According to Olympiou & Zacharia (2014), a blended combination of virtual and real experiments demands a thorough assessment of the objectives of each experiment, its characteristics, skills, and prior knowledge of the learners.

However, many authors refrain from concluding the effectiveness of blended experiments and claim further research is needed to draw a safer conclusion. For instance, a study was conducted to investigate the effect of virtual laboratories on student achievement in chemistry courses (Bortnik et al., 2017). The findings revealed that combining virtual and real laboratories has benefits in terms of meeting learning objectives. But, the authors were hesitant to draw a conclusion, admitting that their study had limitations and recommending additional research in the field. Other authors claimed that it is not the type of manipulative used but rather the extra time spent at work, additional instructional materials used, and innovative instructional strategies employed that might be attributed to the positive contribution (Wörner et al., 2022; Means et al., 2009).

Many research findings revealed that conventional teaching and learning strategies, which are didactic in nature, were found to be ineffective for students' learning. A lot of research has been conducted to alleviate the shortcomings and come up with better learning strategies. The main goals of physics education research are content, teaching and learning strategies, teaching and learning materials, and assessments. Blended learning is one of the alternative teaching strategies in this digital age that can be implemented in favor of conventional didactic teaching in order to improve students' learning. The recent advancement of technology and its application to the education system have brought significant changes to the teaching and learning cultures of schools and institutions. Conventional teaching and learning methods have been modified and increasingly substituted by blended learning approaches.

2.10. Debates regarding the different modes of laboratory experiments

Many studies have been conducted to compare blended learning to conventional teaching and learning methods. They prepare many things for the new method, such as instructional strategies, materials, and resources, while maintaining the existing ones. When the newly proposed mode of laboratory experimentation is implemented as a regular activity, it faces numerous challenges. As a result, it is concerning that education quality has not improved despite the large number of studies conducted by graduates, researchers, scholars, and educational institutions.

Some of the positive outcomes of blended learning were achieved through survey methods, which included responses from teachers and students. For example, Chen et al. (2020) conducted a study to analyze the perceptions of students regarding whether or not blended laboratory courses help them overcome the obstacles they face when compared to conventional laboratory courses. The laboratory course for the blended group was designed with various opportunities, such as an online description of the experiment before class, an exam of about ten questions before class, a series of mini videos, and continuous help from the teacher. In the traditional laboratory course, students individually finish the same required reading before class, teachers administer a quiz, and teachers give a short lecture. More than half of the students (63.01%) thought that blended laboratory classes were beneficial in achieving learning objectives than traditional courses. When compared to conventional teaching methods, the majority of teachers reported that the interest of students in experimentation operations, confidence, hands-on skills, and other aspects were significantly improved.

According to studies, the blended laboratory approach produced better learning results than a solely virtual and real laboratory (Atanas, 2018; Olympiou & Zacharia, 2012; Zacharia et al., 2008). The literature has covered a number of advantages and disadvantages of both virtual and real physics experiments, indicating that each may provide different benefits to strengthen physics learning. It is obvious that there are instances in which virtual investigations may be as successful as or even superior to real laboratory experiments and instances in which real laboratories are more suitable (De Jong et al., 2013). As a result, it is suggested that blending real and virtual physics experiments offers benefits that neither one alone can adequately realize. The effects of different types of physics laboratory experiments (real, virtual, blended) were investigated in various physics topics and concepts such as direct current circuits (Zacharia & Michael, 2016), heat and temperature (Zacharia et al., 2008), light and color (Olympiou & Zacharia, 2012), moon phases (Bell & Trundle, 2008), simple machines such as pulleys (Gire et al., 2010), collisions (Marshall & Young, 2006), and electricity and magnetism course (Atanas, 2018). The studies took different approaches, and the findings were mixed, recommending more research into the effects of different manipulatives on student learning at various levels.

Jaakkola & Nurmi (2008) carried out a study to determine if it would be more advantageous to combine virtual and real laboratory activities while teaching the concepts of basic electricity to elementary school students than to utilize them alone. The findings demonstrated that using a combination of real and virtual laboratory activities together resulted in statistically larger learning gains than using either one alone. In this study, the students were requested to repeat the experiments using real materials and equipment after completing the virtual laboratory activity.

Jaakkola et al. (2011) also carried out a study to compare students’ learning outcomes using a simulation alone compared with a simulation in parallel with real experiments mediated by implicit instructions, explicit instructions, and merely procedural guidance. The results revealed that, in comparison to both virtual experiments with and without explicit instructions, the combination of real and virtual experiments led to better conceptual understanding even when it was not backed by those explicit instructions. However, in the virtual experiment situations, students who received explicit instructions improved their conceptual understanding of electric circuits more than those who received just implicit information. Students were asked to construct every circuit twice, once using simulation and then using real equipment, in both implicit and explicit experiments that combined real and virtual experiments.

However, the studies of Jaakkola et al. (2011) and Jaakkola et al. (2008) have been challenged by the fact that the time on task was not the same for the parallel usage of the combination and the solely virtual and real conditions. The criticism notably focuses on the notion that it is difficult to attribute the positive effects of the virtual and real experiments on students' learning exclusively to the parallel combination of virtual and real experiments. This is because the students in the VE and RE conditions repeated each experiment, increasing their time on task compared to those using VE or RE alone.

Scholars conducted a systematic review of 42 experimental studies with the purpose of comparing the relative efficacy of combining virtual and real experiments with that of using only one type of experimentation (Wörner et al., 2022). Education levels ranging from third-grade elementary school to postgraduate university were covered by the papers included in the systematic review. The majority of the research included in this study was carried out in the USA, followed by Cyprus. Conceptual understanding was the variable that was measured across all 42 studies that were included, whereas attitude was only found in one study, and understanding of the nature of science was not examined. Learner characteristics, aspects of the learning material, and level of guidance or supervision are a few possible confounders that are commonly cited for further research but rarely systematically examined. The low prior knowledge and poor digital device handling abilities of participants, the inadequate reliability of the test instruments, the wide range of prior knowledge in the subject among the students, and the limited number of participants were problems that were commonly noted as impeding learning. If the problems mentioned thereto were flaws in the studies described in the systematic review, they undoubtedly produced uncertain results that call for further research in the field.

In a systematic review of studies contrasting RE versus RE+VE, the combination of real experiments and virtual experiments was compared to using only real experiments, and the results revealed that students in the combined laboratory experiments greatly outperformed those using the real experiment alone on tests of conceptual understanding (Wörner et al., 2022). Scholars such as Gumilar et al. (2019), Zacharia & Michael (2016), Olympiou & Zacharia (2014, 2012), and Farrokhnia & Esmailpour (2010) found that students exposed to blended experiments performed better than those exposed to RE and VE alone. Even though these studies demonstrated that the blended experiment had favorable outcomes, the authors urge more research on the issue. For instance, Zacharia and Michael (2016) noted that conducting research on VE and their relationship with RE across different ages, different subject domains, a larger sample size, and manipulative types is becoming an imperative need. This may come with success given the increasing usage of computer technology in scientific instruction.

However, a study conducted by Darrah et al. (2014) found no significant differences between the learning outcomes of the comparison and treatment groups. Another study compared the effects of using virtual experiments (VE), real experiments (RE), and two sequential combinations of RE and VE on pre-service primary school teachers' understanding of concepts related to heat and temperature (Olympiou & Zacharia, 2010). According to the findings, experimenting with RE, VE, and the two sequential combinations of RE and VE were all equally beneficial in helping students develop their conceptual understanding of heat and temperature.

Makransky et al. (2016) carried out an investigation to determine if a virtual laboratory simulation might take the place of a face-to-face demonstration to get students ready for a microbiology laboratory exercise. The authors compared RE to a single VE and RE sequence. The results showed that there were no significant differences in the laboratory scores between the two groups, and both groups achieved comparable gains in the variables measured. The results suggested that the results indicate that virtual laboratory simulations may be utilized in place of face-to-face demonstrations and that the future of science education could involve a blend of virtual and real laboratory activities.

In a doctoral research, a researcher examined how community college students learned about induction in the field of physics by comparing one group that received a VE before the RE and another group that received an overview presentation before the RE (Pineda, 2015). The findings showed that students who received an overview presentation before performing the RE performed better than those using a simulation prior to doing the RE. According to the author, neither group of students appeared to benefit significantly from the RE; rather, it was the overview presentation that facilitated conceptual understanding. In addition, the VE+RE group struggled to handle the complexity of the VE due to a lack of time and inadequate knowledge of computer simulations. On the one hand, it was difficult to tell whether the change was due to the intervention or not because the comparison and treatment groups were not subjected to the same instructional strategies. On the other hand, this research offers a hint that the type of instructional method or guidance may have been just as crucial as the type of laboratory experiment in explaining the change in learning.

Researchers have identified the attributes that undergraduate engineering students who are studying magnetism, mechanics, and optics courses are most likely to embrace while using blended laboratories (Raman et al., 2014). The findings showed a substantial correlation between the learning outcomes of the blended laboratory and innovation features such as relative advantage, compatibility, ease of use, departmental support, and faculty support. Although the ordering of real laboratory and virtual laboratory within blended laboratory was not significant, learning results under blended laboratory are quite good as compared to real laboratory. When compared to using exclusively real laboratories, students often showed a far more positive attitude toward adopting the blended laboratory approach.

Scholars identified issues that were frequently reported, potential topics for more research, implications, and conclusions after conducting a thorough review of prior studies (Wörner et al., 2022). Given that instruction, scaffolds, and guidance are crucial components of inquiry learning, the authors recommended that future studies take a more systematic approach to the types of assistance and guidance that should be provided to learners when they are using combinations of RE and VE. Additionally, research on individuals other than undergraduate students, teams from additional nations, the time-on-task issue, and other topics should be undertaken. Due to the growing use of computers in science classrooms and the benefits they offer, new technologies need more investigation since they pose novel research questions (Zacharia & Michael, 2016; Zacharia & De Jong, 2014; De Jong et al., 2013).

Other studies reported that students taught using virtual groups outperformed those taught using blended or conventional approaches. For example, a study was carried out to compare the effects of simulation-based, blended, and lecture-based training on midwives' performance on medical issues during pregnancy. The simulation group was taught using a framework of pre-lecture, simulation, observation, and feedback for a total of 6 hours. The blended group was taught with 4 hours of lecture followed by 2 hours of educational website. And the lecture-based group was taught with a lecture-based method through PowerPoint (Tabatabaeian et al., 2018). The findings demonstrated that participants' performance improved significantly in all three groups two weeks following the intervention. Similarly, the intergroup comparison results revealed that the mean scores of participants in the simulation group was considerably greater than in the blended and lecture groups, and it was higher in the blended group than in the lecture-based group. Despite the fact that this study was conducted on medical concerns in a different domain, it used a quasi-experimental design and will provide insights into the current study. The authors, for example, claimed that the constraints of e-learning, such as face-to-face communications and human and emotional interactions, had been greatly decreased. They recommended that a student-centered education strategy can boost learner satisfaction, accelerate learning, develop problem-solving abilities, and promote ongoing learning and critical thinking.

Several studies have emphasized how crucial it is to give appropriate guidance for the learning process in physics laboratory experiments in order for it to be successful (Alkhaldi et al., 2016; Zacharia, 2015; De Jong et al., 2013). This is a critical explanation for teachers to carefully plan the blending of RE and VE in order to meet the desired learning objectives. For instance, De Jong et al. (2013) noted that students who learn through carefully planned blends of real and virtual experiments perform better than those who learn through either type of experiment alone. There was no significant difference in posttests scores of conceptual understanding across the groups, according to many other studies, including Zacharia & De Jong (2014) and Zacharia & Olympiou (2011). For instance, Zacharia and Olympiou (2011) conducted research on real manipulative experimentation, virtual manipulative experimentation, two sequential combination experiments, virtual manipulative experimentation, and control conditions. The findings showed that, compared to the control condition, all four experimental settings were superior at helping students understand concepts relating to heat and temperature.

Other authors stated that blended learning in general can be effective and a solution for our future education system if it meets the necessary requirements. For instance, according to Lalima & Dangwal (2017), because blended learning integrates various modalities, it is complex, and arranging it is a challenging task that requires rigorous efforts, an appropriate attitude, a substantial budget, and highly motivated students and teachers for its successful implementation. The authors came to the conclusion that it has the possibility of becoming an integral part of our educational system if implemented in a well-planned and organized way with the proper attitudes. It can be determined that blended learning necessitates extra time for task completion on the part of both the teacher and the students, as well as the development of additional resources that complement the various modes, the availability of appropriate facilities, and other requirements.

In some studies, the treatment and comparison groups received very different instructional strategies. For example, a study was conducted to investigate the impact of blended learning on college students' achievement using various physics topics (Alsalhi et al., 2021). The study used a quasi-experimental case study design with two groups: one treatment (N = 59) that was taught with a blended strategy and the other comparison (N = 57) that was taught with a direct traditional teaching method for 14 weeks. The findings showed statistically significant differences in favor of the treatment groups. The authors advocated for more research on blended learning in colleges and higher education institutions. However, the time spent on task and the strategy used in the two study groups were different. Students in the treatment group learned about the topics through lecture presentations, worksheets, activities, YouTube, PowerPoint presentations, and online quizzes. Furthermore, students were engaged to examine posted videos on the website and were active in posting their critical reviews of the videos. The comparison group, on the other hand, received only face-to-face, direct traditional teaching. We are unsure what caused the change in student achievement with these differences between study groups. That is, we do not know whether the change in students' achievement was caused by the quality of instructional materials, the extra time spent, or the facilitation techniques.

In contrast, other studies' findings revealed that the implementation of blended learning had no significant impact on students' academic performance between the two approaches (Wei et al., 2017). Moreover, a study was carried out to compare the academic performance of students taught in blended and traditional learning environments. The findings revealed that there was no significant difference between the two groups at the end of the intervention, though there was a mean difference in favor of the blended approach (Kazu & Demirkol, 2014).

In conclusion, despite the fact that there are different modalities, many research findings tend to conclude that blended learning benefits student learning more than solely using online, offline, and face-to-face instruction. Means et al. (2009) found that the students in online environments achieved marginally better than those who received face-to-face instruction in a meta-analysis study. Studies that compared online and face-to-face instructions to only face-to-face instructions revealed larger differences in favor of the blended approach. These blended conditions, according to the authors, often included extra time for learning and other instructional components that students did not get in comparison settings. This result suggests that the positive effects of blended learning should not be ascribed to the media as a whole. According to the authors, the observed advantage of blended learning conditions may be due to differences in content, learning time, and pedagogy rather than differences in media used. However, explanations of this result should recognize that the face-to-face and online conditions differed on a number of factors, including the duration of time students spent on task for the comparison and treatment groups, curriculum materials, and pedagogical aspects. Furthermore, while the studies in the meta-analysis used strong quasi-experimental or experimental research designs, many of them had flaws such as small sample sizes, failure to disclose retention for students in the situations being compared, and potential bias due to the authors' dual roles as experimenter and teacher.

In the current study, concepts of electricity and magnetism from Experimental Physics II (Physics 211) were used. Specific activities in the course syllabus include charging methods, measuring current and voltage, Ohm's law, factors influencing the resistance of a conductor, series and parallel combinations of resistors, electromotive force and internal resistance, determining the direction of the magnetic field of a straight current-carrying wire using a compass needle, electromagnets, and electromagnetic induction.

2.11. Electricity and Magnetism

Students in Ethiopian primary schools begin learning about electricity and charging objects in environmental (grades 1-4) and integrated science (grades 5–6) subjects. In addition, students in upper primary school learn about electricity and magnetism (grades 7 and 8). These topics are also covered in secondary and preparatory schools. Thus, pre-service teachers are familiar with the concepts of charges and charging, electrostatics, and electricity. They came into contact with these phenomena earlier in their lives. Magnetism is also used in many electrical appliances that we use in our homes. Many physics education studies have found that this experiences are starting points for developing misconceptions. Charges and electrical charging are foundational concepts for other concepts such as electric field, electric current and voltage, and electrical capacity and capacitors. As a result, many physics education researchers concentrate on the concepts of electricity to investigate students' knowledge and understanding in order to obtain a clear and sound understanding of the phenomena.

Physics is still regarded by students as an abstract, challenging, and unappealing subject. As a result, unfavorable attitudes toward the subject emerge. Electricity and magnetism concepts are regarded as one of the most difficult aspects of physics because of their abstract nature. There have been a number of studies on how students understand the concepts of electricity and magnetism, as well as a number of methods of instruction for conceptual change in this domain. Certain misconceptions, however, persist even after being treated with the previously mentioned instructional methodologies (Mbonyiryivuze et al., 2019; Eshetu & Alemu, 2018).

Our understanding of the concepts in the study of physics is based on how we interpret the events and phenomena that occur in the physical world. Many studies on science and physics education have demonstrated the failure of conventional teaching strategies (Bao & Koenig, 2019; Faour & Ayoubi, 2018; Fan, 2015). These results showed how poorly science concepts and processes were grasped by students when they were taught using the conventional approach of teaching and demonstrations. One of the most effective ways to make difficult theories easier to understand is to use laboratory experiments (McDermott, 2001), which could also promote meaningful learning (NSTA, 2007). There are various challenges that prevent students from studying science in general and physics in particular, including inadequate laboratory equipment, a shortage of skilled manpower, outdated equipment, an abundance of content, ineffective teaching strategies, and others. A different kind of laboratory experiment termed a virtual laboratory experiment is suggested as a way to get around some of the difficulties after the development of ICT and the potential it offers (Faour & Ayoubi, 2018). The use of technology in an effort to provide quality physics education is supported by virtual laboratory activities that are founded on inquiry-based learning, mostly due to the growing significance of increasing students' motivation and engagement in physics instruction.

It has been documented that a large number of students in many developing countries do not gain the required understanding of concepts in physics when questioned to solve problems. To enhance students' conceptual grasp of concepts electricity and magnetism, different instructional methods have been utilized. However, a major topic that remains mainly unexplored is whether instructional practices that result in high gains of conceptual understanding have long-term consequences (Pollock, 2009). The finding revealed that students' performance may characterize some kind of rote learning of concepts that would likely vanish across time scales considerably longer than the exam duration of individual classes using pre-post testing.

One of the suggested treatments for students' misconceptions about electricity and magnetism is the identification and explanation of misconceptions and background knowledge. This process allows a teacher to enhance the instructional process for a greater degree of conceptual development (Mbonyiryivuze et al., 2019). Authors have reported that some misconceptions arise from the country’s language, culture, and instructional strategies (Mbonyiryivuze et al., 2019; Küçüközer & Kocakülah, 2007). Therefore, assessing students’ prior knowledge based on their culture and language and designing activities aiming to overcome these misconceptions is very important. Finally, more research into the long-term effects of proposed effective instructional strategies for enhancing conceptual understanding across different domains, including electricity and magnetism is deemed necessary.

The topics of electricity and magnetism, particularly direct current electricity, have a strong concern on alternative conception research because, on the one hand, this area of physics curricula is covered in all levels of education. Electricity concepts, on the other hand, are particularly challenging since they are highly abstract and complex (Mbonyiryivuze et al., 2019; Gunstone et al., 2009). Studies show that many physics pre-service teachers find it difficult to understand electricity and magnetism and lack practical understanding of equipment and materials (Takaoglu, 2017).

A study was conducted to compare variations in conceptual understanding of dc electrical circuits among pre-service elementary school teachers in virtual and real laboratory learning environments (Başer & Durmuş, 2010). It was a pretest-posttest quasi-experimental design with two groups: one with a virtual laboratory environment (N = 42) and another with a real laboratory environment (N = 38). After three weeks of inquiry-based physics, both groups demonstrated the same effects on scientific concept acquisition.

Different learning outcomes from physics practical work and laboratory education include conceptual understanding, perspectives on the nature of science, and attitudes toward physics laboratories. It is difficult to assess multiple learning outcomes in a single research project. As a result, in this study, some selected learning outcomes were measured as dependent variables. As discussed in Section 2.12, different learning outcomes are expected from practical work and laboratory experiments in physics. Conceptual understanding, understanding the nature of science, and attitude toward the physics laboratory were chosen for this dissertation. Though conceptual understanding has been extensively researched in the research literature, it was chosen as the basic learning outcome. Understanding of the nature of science is especially important for pre-service physics teachers, as they are the ones who are expected to lay the foundation for children. A solid understanding of NOS enables them to examine primary school children's misconceptions and devise change mechanisms. Furthermore, pre-service physics teachers are more likely to influence children if they have a positive attitude toward practical work and experiments. Furthermore, affective variables have a positive correlation with achievement.

2.12. Educational goals of practical work and laboratory experiments

Different authors remarked about the relationship between experiments, laboratory work, and practical work in curriculum of physics education (Vilaythong, 2011; Meester & Kirschner, 1995). However, there is no consensus among physics education researchers and authorities on the goals of introductory physics laboratory and the way to assess these goals (Hanif et al., 2009). For instance, The American Association of Physics Teachers has identified the following five shared goals (AAPT, 1998): conceptual learning, the art of experimenting, understanding the foundations of knowledge in physics, experimental and analytical skills, and fostering collaborative learning abilities. For instance, the goal for the art of experimentation stipulates that every student should have meaningful expertise with experimental processes, including some hands-on inquiry design investigations.

Though these aims encompass generally acceptable skills, they are very general and difficult to be attainable below the age of 16 (Hanif et al., 2009). The National Research Council (NRC, 2005) again suggested common goals of physics laboratory. The objectives of laboratory experiences for science learning include fostering interest in science, boosting mastery of science subject matter, enhancing scientific reasoning skills, promoting understanding of the ambiguity and complexity of empirical work, improving practical skills, enhancing teamwork skills, and increasing understanding of the NOS. In sum, it can be implied that there is no agreement among physics education researchers and other scholars in different countries with regard to educational goals and the best way to assess the outcome of those goals for physics laboratories.

Practical work and laboratory experiments have found an essential place in the teaching and learning of science in schools and higher education institutions. Though there are no agreements in terminology and definitions, many scholars claimed that laboratory experiences in physics help search for answers and provide insights into phenomena in the natural world the same way as physicists do (Vilaythong, 2011). Many authors reported that the contribution of practical work to science education was investigated starting from its onset beginning the 18th century (Shana & Abulibdeh, 2020). Accordingly, practical work offers many gains such as increasing laboratory knowledge and skills, understanding science concepts and theories (Schwichow et al., 2016), stimulate students' positive attitudes and increase motivation that can affect students' achievement in science (Twahirwa & Twizeyimana, 2020; Antwi et al., 2021).

Most importantly, emphasis should be put in pre-service teacher education on improving various laboratory learning outcomes. Preparing pre-service physics teachers to effectively teach experiments in a physics laboratory necessitates initiatives. The goal could be to improve conceptual understanding of physics concepts, as well as the knowledge and skills required to lead laboratory experiences (Gkioka, 2019), to foster a positive attitude and motivation toward physics and laboratories (Saputra et al., 2020; Freedman, 1997), and to improve understanding of the nature of science (Abd-El-Khalick et al., 2004).

In many countries, there is great concern about science, technology and mathematics education and improving students' performance in these fields. Though physics is fundamental to ensure future needs for scientific and technological competency of a nation, students in various countries experience a drop in their performance in international assessments such as Organization for Economic Co-operation Development (OECD) and Trends in International Mathematics and Science Study (TIMMS) (Bigozzi et al., 2018). According to the authors, students recognize that science plays substantive role for the society though their performance is not good and depend on how science is taught to them in schools. Following this and other such crises, researchers in science education proposed reformed instructional strategies based on empirical and theoretical evidence.

The willingness and ability of teachers to implement reformed instructional practices will have a significant impact on the outcome of a curriculum. Inquiry-based (Sreedevi & Sudhir, 2011; Abd-El-Khalick et al., 2004), interactive engagements, (Volkwyn, 2020; Sokołowska & Michelini, 2018; Hake, 1998), and interactive simulations (Volkwyn, 2020; Sokołowska & Michelini, 2018; Sreedevi & Sudhir, 2011) are some of the examples of these strategies. In sum, the practical, empirical, and theoretical evidences of the role of practical work in physics assure the useful role of practical and laboratory activities in physics education. If this is the case, adequate pre-service physics teacher preparation should be considered in order to improve the overall quality of physics instruction. This is due to the fact that these teachers set the foundation, and no education system could exceed the quality of its teachers.

It has been demonstrated that physics practical and laboratory activities improve students' learning and effectiveness. Of course, there are differences in the purpose, epistemological role, and implementation. Despite the fact that practical work and laboratory activities yield different outcomes, the focus of this study was conceptual understanding, the nature of science, and attitudes. Physics education places a strong emphasis on conceptual understanding. The nature of science is also crucial. It is particularly important for pre-service teachers because their perspectives on the nature of science influence their teaching and learning. Aside from cognitive effects, affective factors play an important role in preparing quality teachers. The sections that follow go over each learning outcome in detail.

2.12.1. Conceptual understanding

One of the objectives of physics education at all levels of the education system should be conceptual understanding (Gabel, 2003). The author further emphasized that science can be understood at the phenomena (macroscopic), the particle (microscopic) and the symbolic level. Many authors considered conceptual understanding as a major focus of student learning in physics. For example, known physics educators (McDermott & Redish, 1999) prepared a resource letter that contains an overview of research on the learning and teaching of physics that can add value to the ongoing improvement and enrichment of student learning in physics. The resource letter focused on various categories which vary in scope and type including conceptual understanding, problem solving performance, efficacy of laboratory education and lecture demonstration, ability to use mathematical knowledge and skills in physics, beliefs and attitudes of students, and reflections on research into student reasoning.

Using the FCI test, a study was conducted to investigate pre-service physics teachers' misconceptions and causes in force and motion concepts in Jordanian universities (Mohammad et al., 2020). Conventional instructions, according to the authors, may add to students' alternative conceptions, and thus new instructional strategies must be considered to inspire conceptual understanding of pre-service physics teachers. After comparing different cultural backgrounds of students, they concluded that the various misconceptions of some physics topics were universal in nature. Educational backgrounds, language, ages, gender, preconceived notions, naive theories, non-scientific beliefs, mixed conceptions, and cultural upbringing all influence conceptual understanding of students in science (Docktor & Kenneth, 2008). Teachers' conceptual understanding is one of several variables that influence instructional effectiveness. As a result, teachers should be adequately prepared in terms of conceptual understanding of various physics concepts. Different data collection instruments for a variety of physics topics can be used when deciding to use conceptual understanding to examine the effectiveness of an intervention. Standardized multiple-choice tests are the most commonly used.

Many studies have revealed that students' responses to standardized conceptual multiple-choice tests such as FCI and conceptual understanding of EM are neither coherent nor completely random. According to the authors, there is evidence that the cognitive conflict strategy was unable to change students' alternative conceptions because their responses were inconsistent with EM conceptual tests. They found that cognitive perturbation through the use of interactive simulations facilitates conceptual change more effectively than cognitive conflict through the use of interactive simulations (Dega et al., 2013).

Before we get into the definition and meaning of conceptual understanding, let's look at the definition of concepts. According to Merriam-Collegiate Webster's Dictionary (2012), a concept is something that is conceived or an abstract or general idea that can be generalized from specific occurrences. Others, like Westwood, cited in (Hurrell, 2021) stated a concept as a mental model that encompasses all of an object's, a situation's, or an idea's important characteristics. Concepts help us to categorize phenomena into groups according to whether they belong together or not. Concepts are characteristics that govern whether something is included in or excluded from a set or class, according to Chinn, who was referenced in Hurrell (2021).Understanding of these concepts is known as conceptual understanding (Rittle-Johnson & Schneider, 2015). In the review of the literature on mathematics education research, the NRC used a similar definition, stating that conceptual understanding is the comprehension of mathematical concepts, relations, and operations (NRC, 2001).

Many of the previous works the researcher looked related to conceptual understanding were those conducted in mathematics subject and a limited ones in physics. Though the words concept and conceptual understanding are frequently used in physics classrooms, there is no agreed up on definition for the two terms in the literature (Sands, 2014). Scholars suggest that understanding a concept in isolation is difficult and does not make sense so that conceptual understanding depends on the context in which the students are engaged. In this regard, scholars who have conducted a research using the force concept inventory (FCI) have revealed that students who seem to understand a physics concept in a given context can be unsuccessful in providing the same reason in another context *even measured with the same test* (Sands, 2014).

Experimental activities in physics facilitate the students to advance their learning of facts, concepts and procedures. According to Anderson et al. (2001) knowledge dimensions, there are four levels of knowledge: metacognitive, procedural, conceptual, and factual. Factual knowledge is basic information about a discipline, physics in this case, that students need to know and includes terminologies, specific details and elements of the subject. It helps as a basic building block to understand higher relationships in a discipline. An integrated and practical understanding of concepts is referred to as conceptual knowledge. Students who have a conceptual understanding of the subject matter can identify how concepts and procedures relate to one another and can make a case for why one fact follows from another while another does not.

Conceptual understanding was one of the outcomes or dependent variables used by the researcher to assess the effectiveness of blended real and virtual laboratory experimentation. It refers to an integrated and functional understanding of physics concepts measured using multiple choice test items. Students with conceptual understanding consolidate their knowledge into articulate entire which enables them to connect new ideas to what they already know (NRC, 2001). Students who have conceptual understanding know significantly more than students who only know isolated facts and techniques because they have an integrated and practical comprehension of ideas. In addition, learning with conceptual understanding enhances retention, can easily remember and use it when necessary and reconstruct it if forgotten since fats and methods are already connected. Understanding the key concepts and how they relate is the foundation of a solid conceptual understanding of physics, which is especially useful in designing how and in what sequence to start introducing concepts in teaching (Koponen & Nousiainen, 2013). As a result, learning with understanding is believed to be more powerful than simple memorization of facts and methods.

The issue of conceptual understanding is also the concern of constructivist learning, Constructivist learning theorists are not interested in small and unconnected constituents of public knowledge, but in acquiring, capable of understanding, and applying large bodies of conceptually organized public knowledge such as Newtonian mechanics and kinetic theory of gases (Pines & West, 1986). The authors further explained that constructivists are concerned with the conception that learners' prior experience is an essential condition (in their own aphorism, *sine qua non*) to construct meaning and new knowledge. That is, the individuals' prior private knowledge can be a determining bridge to new knowledge either being an enhancing a barrier factor. Following that, it would be consistent with constructivist learning theory to choose conceptual understanding as a dependent variable to assess the efficacy of physics laboratory experimentation modes.

Although it is not always possible to separate between conceptual and procedural knowledge, doing so can help us better understand how knowledge develops (Rittle-Johnson & Schneider, 2015). Conceptual knowledge comprises the understanding of concepts as well as the depth and breadth of their connections (Star, 2005). It can be viewed as a network of interconnected knowledge made up of separate pieces of information and the connections that link them. Whereas a procedure is a set of actions or steps executed to accomplish a goal, procedural knowledge refers to the understanding of procedures (Canobi, 2009). The procedures may involve algorithms, which are established sets of actions that, when correctly carried out, result in the correct answer, or they could be potential steps that need to be taken in the right order to solve a specific problem, like steps for solving equations (Rittle-Johnson & Schneider, 2015).

Research on the relationships between conceptual and procedural knowledge has revealed four distinct theoretical stances, each of which has its own proponents and some empirical support (Rittle-Johnson & Schneider, 2015). Concepts-first viewpoints hold that students first pick up conceptual information, which they subsequently use to derive and create procedural knowledge through repeated practice solving problems. The second is procedures-first views, which contend students should first learn how to do things before gradually deriving conceptual understanding from those things through abstraction processes. The inactivation perspective, which is the third point of view, contends that procedural and conceptual knowledge are formed independently. The fourth is an iterative view, which claims that causal relationships are bi-directional, meaning that growing conceptual knowledge prompts growing procedural knowledge and vice versa.

The next question that comes to mind of a researcher is how to measure conceptual understanding of pre-service physics teachers. Conceptual understanding can be measured using in an implicit or explicit ways. According to (Rittle-Johnson & Schneider, 2015), evaluation tasks that demand children to make a categorical choice, a quality rating, translate between representational formats, and compare quantities are frequently used to measure implicit conceptual knowledge. Providing explanations and definitions for concepts and terms, illustrating how a process works, or constructing a concept map are a few examples of explicit measurements of conceptual understanding. These tasks can be accomplished verbally on standardized interviews or on a paper-and-pencil assessments.

Previous researchers designed and developed a number of instruments for assessing students' understanding of physics concepts. Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney et al., 2001), Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT), and Brief Electricity and Magnetism Assessment (BEMA) (Ding et al., 2006) are some of the tools found to assess students' conceptual understanding of electricity and magnetism concepts. The authors claim that the BEMA is a reliable test that is frequently used by physics education researchers and that it covers a wide variety of fundamental ideas in electricity and magnetism. As stated by (Von Korff, et al., 2016), to make sure that their attempts to measure conceptual understanding of students are productive and result in valid conclusions, teachers and researchers must use well-developed assessment instruments in their research.

For the current study, conceptual understanding items were adapted from literature in the domains of electricity and magnetism in accordance with the topics of the laboratory activities. PhysPort, developed by the American Association of Physics Teachers, permitted the researcher permission to use assessment resources based on physics education research (PER) via e-mail. To ensure representativeness of the test, additional items were taken from standardized textbooks and validated. Many factors influence students' conceptual understanding of physics concepts, including the teaching method (Bigozzi et al., 2018; Kola, 2017). It is essential to assess pre-service physics teachers' conceptual understanding of physics because they will be the physics teachers of the future and be responsible for teaching physics to students in the years to come (Aviyanti, 2020).

2.12.2. Understanding of the nature of science

Formerly, history and philosophy of science were used to explain the interaction of science and inform science education on the attributes of science, but lately, nature of science (NOS) has been employed to represent the scientific enterprise. NOS is not mainly focused on the natural world; rather, it is a rich amalgam of many areas of social studies of science, such as history, sociology, and philosophy of science, combined with studies from cognitive sciences like psychology (McComas, 2006). Scholars claim that understanding of the NOS is a fundamental element of scientific literacy implying that cultivating scientific literacy of students is taken as the eternal goal of science education globally. Scholars suggest that NOS aspects could be offered as a standalone course or as history and philosophy of science course (Mudavanhu & Zezekwa, 2017) or it can be offered as a kind of subject matter knowledge (Abd-El-Khalick, 2001). Besides, scholars classified NOS views into two: modern NOS views and traditional NOS views. The conventional NOS approach is based on rationalism and emphasizes evidence, experience, and induction, whereas the modern NOS view is based on constructivism and emphasizes the temporary and subjective nature of scientific knowledge (Zhang et al., 2021).

There has been no consensus in the literature on what NOS is (Irzik & Nola, 2011; Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000). The definition of NOS is unresolved, but it can be defined through its aspects (Seker & Welsh, 2005). Many science educators, however, have adopted what is known as the consensus view about the NOS, which aims to teach students only those aspects of science on which there is broad agreement (Irzik & Nola, 2011).

Three approaches to teaching the NOS have been identified in the literature: implicit, explicit-reflective, and historical approaches. Students can learn about NOS using the implicit approach by participating in scientific activities such as experimentation and observation in their science lessons. NOS and its aspects should be explicitly integrated into the science course in the explicit-reflective approach, and these activities should be addressed through whole-class discussion. The historical approach entails teaching NOS through the use of examples, such as incorporating interesting events from the history of science and holding discussions about those special events (Sardag et al., 2014). In addition, scholars claimed that there is no one-size-fits-all approach in improving scientific literacy and active engagement of students (Glaze, 2018). The author suggested that using technology as it provides many resources and opportunities such as interactive simulations that can shift learning from passive to active; rethink about laboratory activities to enable students for inquiry and discovery approach over procedures that lead to fixed results; and intentional incorporation of NOS, philosophy of science and history of science as a stand-alone course or with the content in a course would provide would lead to enhance scientific literacy.

The epistemology and sociology of science are used to characterize the nature of science. The former refers to science as a method of knowledge, and the latter relates to the beliefs and values that are integral to scientific knowledge and how it evolves (Lederman, 1992). The author claimed that the characterizations of the NOS remain general and that there are disagreements regarding specific issues of the NOS among different groups of scholars, such as historians, philosophers, and sociologists of science. The author further added that pedagogic form, more than any other aspect of science, has determined our image of the nature of science and the role of discovery and invention in its advancement. Given the multifaceted and complex nature of science, such a debate should not be surprising or upsetting. Considering the varied, complicated, and dynamic nature of science, this lack of agreement should come as no surprise (Abd-El-Khalick & Lederman, 2000). According to Clough & Olson (2008), NOS is a term that science educators use to discuss questions including how science functions, what it is, the ontological and epistemological underpinnings of science, how scientists function, and society's influences and responses to scientific research.

Science generates new knowledge and contributes for the development of scientific literacy which is a societal need irrespective of class whether privileged or marginalized (Chuy et al., 2010). It is repetitively disclosed that scientifically literate citizens who are able to clearly understand the scientific enterprise can be characterized by intelligent participation in political decisions related to science and contribute for informed decisions such as career choices. However, understanding the nature of science continues to be a challenge for teachers and students at different levels (Bybee, 2008; Hodson, 2003). This might be associated with the perception of science by students as a methodological assortment of observations and evidence rather than science as a creative and idea-driven enterprise which in turn provides very little motivation to seek for scientific careers.

Plethora research demonstrates that it was since the early 1960 that major efforts have been embarked on to enhance nature of science views of students in every level of schooling and science teachers (Lederman et al., 2002). Despite the emphasis given by major science education reforms in order to help learners to develop informed views of nature of science, many researches have consistently shown that students in every level as well as science teachers have not attained desired understanding of nature of science. Several attempts have been, and continue to be, undertaken to enhance students' and science teachers' nature of science.

Many scholars argue that the teacher, among other factors, is the critical element in implementing a curriculum. Therefore, it is very important to investigate the nature of the views of science held by pre-service physics teachers since their views determine the way they teach after completing their education. Research about pedagogical content knowledge can and should be influenced by studies on students' and teachers' conceptions of the NOS. More specifically, it is evident from the study of teachers' conceptions that teachers as a group hold a diverse range of conceptions, each with different degrees of complexity and logical coherence (Lederman, 1992). When it comes to physics in particular, an individual's perspective of how physics functions, how it generates knowledge, and what status that knowledge has needs to be investigated. It is also recommended that science teachers help reflect a plurality of views when there is no consensus (McComas, 2006).

Although there are debates concerning the aspects and basic essence of science, Lederman et al. (2013) and Lederman et al. (2002) put forth some tenets that have been agreed upon. These include the fact that scientific knowledge is tentative, empirically based, subjective, requires imagination and creativity, and is rooted in social and cultural contexts. The two additional important aspects are the difference between observations and inferences as well as the purpose and relationship between scientific theories and laws. The tentativeness of scientific knowledge, the scientific method, imagination and creativity, the empirical basis of science, the inferential/theoretical nature of science, subjectivity in science, the distinction between theory and law, and the socio-cultural embeddedness of science are other ways of identification of aspects of the nature of science (Sardag et al., 2014). This demonstrates that there were some commonalities among the identified aspects of the nature of science.

According to McComas (2006), science has a substantial and inescapable impact on every aspect of life from philosophical implications emerging from it ideas and technology that flows from science. Despite the importance mentioned, many individuals have no clear understanding of how the scientific endeavor or enterprise operates which might have substantial effect on policy matters, legal issues and science funding decisions. Research reports revealed that many individuals even from the developed world have limitations regarding views about the nature of science. The reason forwarded behind this poor understanding of nature of science was that teaching of science and science textbooks were at factual recall level which do not facilitate learning; the way how science teachers were educated and even science educators misinterpret the way how science knowledge is produced if they consulted poor textbooks.

Scholars argued that NOS issues should be incorporated in the teaching and learning of science/physics for a number of reasons. Actually, there are debates regarding the way how NOS should be taught for students, implicit or explicit. Many science education researchers have claimed for the addition of nature of science views in science/physics teaching and learning process. According to (Hansson & Leden, 2016), this inclusion can be done either in a separate NOS activities or explicitly by setting up inquiry lessons.

A study was conducted to compare the effectiveness of using history of science on students understanding of the nature of science (Seker & Welsh, 2005). In one group, the teacher used explicit teaching strategies that target aspects of the nature of science, while in the other group, the teacher used teaching strategies that did not explicitly target aspects of the nature of science. The scientific method, tentativeness, inference, and subjectivity were measured, and the percentages of students' naive and informed views were compared across groups. The findings revealed that both implicit and explicit methods of using history of science did not provide conclusive evidence to improve student understanding of the nature of science, despite significant evidence on scientific method and inference. The authors proposed that, rather than explicit or implicit methods of teaching the nature of science, alternative description teaching strategies are required.

The explicit approach uses the aspects of nature of science clearly during the teaching learning process, whereas the implicit approach does not target the nature of science aspects. Several authors advocated for an explicit approach to science history (Khishfe & Abd-El-Khalick, 2002; Abd-El-Khalick & Lederman, 2000). The history of science is a teaching material that can be used both explicitly and implicitly (Seker & Welsh, 2005).

For a long time, science education research has advocated for the incorporation of NOS aspects in teaching and learning for a variety of reasons (Hansson & Leden, 2016; Matthews, 2012). For instance, Hansson & Leden (2016) claimed that students frequently hold views about science that are overly simplistic and are incompatible with scientific explanations. The authors extend that such myths and incompatibilities may not be confronted if teaching emphasizes solely on physics models and concepts, or if students are only involved in conventional laboratory work without also clearly addressing what type of endeavor science is. That is to say, NOS learning must be planned for as a learning objective because it cannot occur automatically. It was explained how learning science differs from learning science to do and from learning about science, and how it might be challenging to keep all these three goals in mind at once (Hodson, 2014). According Hansson & Leden (2016), NOS can be addressed in physics lessons either separately or in conjunction with specific physics content. Separately, NOS activities could be a beneficial way to highlight specific issues. Second, NOS aspects become a part of physics teaching not only during lessons but also in relation to specific concepts and models. The latter approach could be taken by addressing some NOS aspects in relation to, say, laboratory work (Hansson & Leden, 2016; Etkina, 2015; Yacoubian & BouJaoude, 2010).

A study conducted on a one group pretest-posttest design reported that learning about the history of physics enhanced the views of pre-service physics teachers regarding how scientists work in developing scientific knowledge (Tanel, 2013). The available recommendations on how understanding of the nature of science is enhanced are diverse. For instance, studies noted that knowledge of teachers regarding the nature of science are a measure of their scientific epistemological beliefs (Lederman et al., 2002; Lederman, 992). Many teachers face a challenge to apply the process of constructivist learning and teaching since they were themselves educated and in conventional pattern of instruction. It has been revealed that pre-service teachers who have been given education and training in light of constructivist approach, have studied educational psychology, basic elements of education, learning theories, and classroom settings exhibit positive improvement in their epistemological beliefs concerning learning and teaching (Tanel, 2013; Chai et al., 2009). So, recommendations regarding on how understanding the nature of science is improved are diverse. Addressing a wide range of literature review and designing appropriate mechanisms that match to the context can be a solution.

A historical review of the NOS assessment showed that it was initiated in the 1960s using a quantitative approach, which was characteristic of much of science education research at the time. Later on, some open-ended questions were used for validating the items in the instruments, but still little emphasis was given to extracting an expanded view of individuals' views of the nature of science (McComas, 2006). Assessment of students' and science teachers' nature of science views remains an issue in research on NOS. In many of these works, standardized paper-pencil instruments consisting of forced-choice items, such as agree/disagree, Likert-type scales, and multiple choice items, have been implemented to investigate students' and science teachers' views of the nature of science (Lederman et al., 2002). These instruments were criticized from different perspectives, such as their validity and the developers' biases. In order to alleviate such shortcomings, different types of the views of nature science questionnaires were developed and validated by scholars. These open-ended questionnaires are also criticized since these types of instruments are difficult to analyze.

The Ethiopian curriculum does not explicitly state that understanding the nature of science (NOS) is a goal. However, there are terminologies and courses linked to NOS aspects in Ethiopian educational resources. History and Philosophy of Physics and Physics Education, for example, is one of the courses offered for Bachelor of Education (B.Ed.) physics undergraduate students, but it is elective (AAU, 2021). This course is designed to provide pre-service physics teachers with a comprehensive view of the nature of science (NOS). It was shown that curriculum informed by history and philosophy of science improved students' learning in both quantitative and qualitative ways. The learning outcome of this course is to understand and discuss the nature of science (NOS) and the nature of physics as they apply to high school physics education and in general.

Furthermore, the physics curriculum for grades 7 and 8 requires students to participate actively in the teaching and learning process. Students will be able to understand the nature of Physics, apply principles, and develop basic manipulation abilities connected with Physics. And, one of the goals of the grade 9 chemistry curriculum is to give students an important insight into the nature of science by utilizing historical perspectives such as atom components and characteristics (MOE, 2009). Scientific inquiry (ScSi 211) was a course designed for pre-service integrated science teachers who will be teaching lower primary grades 1 to 4. Philosophy of science, understanding the nature of science, scientific inquiry, scientific attitudes and methods are among the topics taught in this course (College Curriculum). To summarize, whereas the nature of science is not explicitly stated as a goal of the Ethiopian curriculum, some terms and courses connected to NOS are included in various educational documents.

Although there aren't many cross-cultural comparison studies on VNOS, researchers found that Chinese science teachers understood NOS differently than Turkish and American science teachers (Liang et al., 2009). Teacher education program and the profile required to become a teacher at different levels of education is different in different countries. It is evident that understanding of the NOS might vary among science teachers across society and cultures. This is because science jointly interacts with culture and society and it is practiced under such a huge cultural background in which the individuals who are engaged in science are the results of this culture (Zhang et al., 2021). It seems that social-cultural embeddedness is one aspect of nature of science because scientists are the result of their culture and what they do as science is influenced by their social values. Therefore, it is very important to study understanding of the nature of science as a learning outcome for two reasons. First, it shows us how pre-service teachers' views about the understanding of the nature of science vary as a result of the interventions. Second, it will provide an insight on how socio-cultural factors affect VNOS.

2.12.3. Attitude towards physics laboratory

Affective domains such as attitude in science education have always been the concern of science education research. According to Kroh and Thomsen (2005), instructional strategies should take into account for the enhancement of cognitive variables as well as affective variables such as attitude and motivation. In addition to enhancing physics learning outcomes, experimentation has positive effects on affective dimensions such as attitude and motivation. Scholars claimed that though many countries included affective objectives in their science curriculum, there is limited research dealing with the way how to improve students’ science-related affective characteristics.

(Güngör, 2010). The author stated many affective characteristics based on previous research, including the interest of students in learning physics, aspirations for physics-related extracurricular activities, physics anxiety, physics test anxiety, student motivation in physics, the importance of physics, physics achievement motivation, and self-esteem consisting of physics self-concept and physics self-efficacy. Though the degree of coverage varies, science education literature has addressed the impacts of teaching methods on students' science achievement, science-related affective characteristics, and other factors such as parents' attitudes towards science.

At different stages of the educational system, a variety of variables contribute to inadequate achievement and enrollment in physics. The attitudes of the students is one of the causes contributing to low enrollment in physics at numerous levels of the educational system, including secondary (Opondo, 2009), pre-service teacher education (Saputra et al., 2020), and undergraduate. Despite the crucial role that physics as a field of science plays in the contributions of inventions and developments necessary to realize the goals of a nation, the discipline is seeing a decline in enrollment and accomplishment. Furthermore, practical work and lab experiments lead to enhanced attitudes toward physics and physics laboratory experimentation (Antwi et al., 2021; Ng'ethe, 2016). Laboratory experiments enhance students' conceptual understanding, science experience, scientific attitudes, and problem-solving skills when they are well implemented (Musasia et al., 2012). It can be thought of as engaging students in handling real or virtual materials and equipment (Millar, 2004). By doing so, these manipulatives enhance attitudes toward both the subject and laboratory experimentation.

Despite its significance, there is a crisis in physics education, and many African nations have poor levels of physics enrollment at all levels. Inadequate teacher preparation is one of the factors that contribute to this problem (Musasia et al., 2012; Semela, 2010). Because of its abstract character, physics in general as well as some of its topics like electricity and magnetism are regarded as challenging, which can result in negative attitudes towards the subject (Mbonyiryivuze et al., 2019). Teachers of physics should assist in fostering in their students a favorable attitude toward the subject so that they are better prepared to understand it. Pre-service physics teachers themselves must get appropriate education and training in order for this to happen. For instance, in a study conducted that used a descriptive quantitative method to look into the attitudes of pre-service physics teachers towards physics laboratory experiments, it was identified that participants possessed unfavorable views in all components of attitude, but only with the exception of the benefits of physics practical work (Saputra et al., 2020). These unfavorable attitudes were related to the design of laboratory experiments for verification that could not result in a better understanding of concepts, interests, and skills.

Better facilitation is required (Millar, 2004); design is just as important as practical aspects. The guided inquiry-based approach is one of the innovative methods of instruction that is used to help students learn practical tasks as effectively as possible. There are various levels of inquiry-based laboratory learning described in the literature, including confirmatory, organized, guided, and open. However, physics laboratory experiments (Rahmi et al., 2018; Ural, 2016) tended to favor guided inquiry-based learning. Additionally, it was noted that different learning outcomes, including attitudes about physics as a subject and physics laboratory experiments, depended on the type of experimentation that was conducted.

Although previous studies have shown that using real instruments and manipulatives helps students better understand science concepts in general, technological advancements have developed new avenues for communicating these ideas, such as virtual and blended modes of laboratory experimentation in physics. The impact of technology-enhanced learning, including virtual simulations and blending of virtual and real experiments, on the learning of physics has produced a range of findings from academics. According to some authors (Zacharia and Olympiou, 2011, Zacharia and Constantinou, 2008, Triona and Klahr, 2003), virtual simulations are just as beneficial as real tools and manipulations. Others claimed that real instruments and manipulations were more beneficial to student learning than virtual ones (Marshall and Young, 2006). Others, including Zacharia and Anderson (2003), Finkelstein et al. (2005), and Olympiou and Zacharia (2012), have suggested that virtual simulations are more beneficial to student learning than real manipulatives. There are authors, however, who thoroughly analyze the advantages of choosing one over the other. For instance, it has been reported that real manipulatives are helpful when active and actual touching of materials is required (Zacharia & Olympiou, 2011), whereas virtual simulations have been found to be beneficial when providing concrete illustrations of abstract concepts and ideas as well as phenomena in nature (Marshall & Young, 2006).

Recent reports claim that the benefits of the two forms of experimentation can be improved by a blended approach. Many of the studies that were done lacked clear instructions on how to accept or reject the results. Blended laboratory experimentation, which combines the benefits of real and virtual manipulatives, has recently been promoted as an improved option (Zacharia & Michael 2016; Olympiou and Zacharia 2012). The findings are still inconclusive. It appears that this method optimizes laboratory experiments for physics learning by taking advantage of each manipulative's benefits. However, there were some criticisms of it as well. According to some authors, the time spent on the task rather than the strategy seems to make the blended approach superior to using each method separately (Means et al., 2009). Other writers claimed that blended physics laboratory experiments improved student learning more than any other strategy, although they lacked confidence. In order to gain a thorough understanding of the problem, authors who have analyzed studies on blended experimentation have come to the opinion that more study must be done. For instance, after reviewing more than 115 studies on both blended and conventional laboratory instruction, Brinson (2015) came to the conclusion that more study was necessary. However, there is a dearth of research on the application of blended physics laboratory experiments to pre-service physics teacher attitudes toward physics laboratories in the Ethiopian context.

Every scientific area puts a lot of effort into developing standard definitions and methods of measurement for different constructs, among which is attitude. This construct has been studied for a very long time, and its definition has changed over time. For instance, it was first understood to include cognitive, affective, motivational, and behavioral aspects and is widely considered a foundational idea in social psychology. The attitude construct was substantially reduced during the following decades to its evaluative component and its modern meaning of likes and dislikes (Schwarz & Bohner, 2001). The definition given in the literature is ambiguous (Altmann, 2008). The author continued by saying that despite the fact that an attitude is usually defined as a mental state, a propensity to a value or belief, and as a belief, value, or feeling, there are no specific characteristics to define the concept. There are numerous definitions offered for attitude, including an established opinion and behavior supporting it (Abate, 1999), a tendency to respond favorably or unfavorably (Kapucu, 2017), and as a combination of emotions, beliefs, and behaviors focused towards a particular person, thing, object, or event (Cherry, 2021).

Again, there are various approaches to determine student learning attitudes for a certain subject. There are two fundamental categories of attitude to take into account: attitude toward science and scientific attitude. The former refers to attitudes that are held about an enterprise, such as a scientific endeavor, school science, the impact of science and technology, or scientists. The latter is a scientific attitude that is open-minded, truthful, or skeptic (Aydeniz and Kotowski, 2014;

Akcay et al., 2010). According to the literature, there are many different definitions and interpretations of the attitude construct used in science education. The interpretation of attitude research in science education has been impacted by the diversity of attitude meaning, which has also impacted the development of reliable and valid measures of attitude toward science (Aydeniz & Kotowski, 2014). It has been demonstrated that a student's attitude toward one or more subjects influences how well they succeed in those subjects. Positive attitude encourages students to put forth effort and results in good accomplishment in that subject, whereas negative attitude makes learning challenging (Xavier & Croix, 2016; Veloo et al., 2015).

Many scholars emphasized the link between learning and attitude. Human behavior is influenced by attitudes, which are connected to regulating and controlling the emotions that emerge during the learning process (Kaya & Boyuk, 2011). The connection between theories of attitude construction and change and learning attitudes has been discussed by a variety of scholars. For instance, Hsu and Huang (2018) explained about functional and cognitive components, with the former focusing on how individual idea variation and individualization are factors in attitude alteration and the latter asserting that attitude construction requires greater reasoning and knowledge. Additionally, there are three elements that make up attitude: the affective, cognitive, and behavioral aspects of a student's work in developing learning and behavioral patterns (Altmann, 2008; Ana Maria, 2008; Shrigley, 1983). Along with the idea that changing attitudes will influence behavior, attitude strength is an important topic to consider. While attitude strength has been studied extensively in the social science literature over the years, it has remained a vague metaphor rather than a properly defined social scientific construct. Despite this ambiguities, the four aspects of attitude namely persistence, resistance, impact on information processing and judgements, and its nature of guiding behavior can be taken as defining features of attitude strength

(Petty & Krosnick, 2014). As a working definition, it is likely to regard attitude strength as the degree to which attitudes exhibit the attributes of durability and impactfulness that the former can be manifested by persistence and resistance whereas the latter was manifested by the influence on information processing and judgments and nature of guiding behavior.

Psychologists have debated whether attitudes can predict behavior for a very long time. According to (Reid & Skryabina, 2002) a student's attitude toward science classes can be a good predictor of whether they plan to enroll in science classes. According to different scholars (for instance, Fishman et al., 2021; Xavier & Croix, 2016; Guido, 2013), there is a connection between behavior and attitude, and this connection can be predicted by causal processes. Science teachers who have an interest in changing attitudes might anticipate a change in behavior because of the causal links between attitude and behavior (Shrigley, 1983). To determine how much an individual reacts favorably or unfavorably to an action, a variety of scales are used. Each participant is given a single number that represents how positively or negatively they feel about a certain course of action once the responses have been averaged. When evaluating attitudes qualitatively or quantitatively, it is crucial to take into account attitudes toward the particular behavior of interest if the ultimate goal is to predict behavior.

The results of earlier studies indicate that while there has been a lot of research on attitudes about physics as a discipline, there hasn't been much done on students' attitudes about physics laboratory experiments (Saputra et al., 2020). The authors claimed that analyzing students' attitudes toward physics laboratory experiments helps in gaining an understanding of what might occur in such activities and experiments. This is due to the finding that there is a statistically significant relationship between student behavior and academic achievement in physics. But, a study by Kaya and Boyuk (2011) on secondary school students' attitudes toward physics classes and experiments indicated that the average scores of attitudes were below the level that was anticipated. However, this study was an assessment that did not go into much detail about what was accomplished. Another study that used an experimental approach to examine preservice teachers' attitudes regarding basic physics laboratory experiments found that students had negative attitudes toward laboratory activities and experiments (Yesilyurt, 2004). Even though it was unclear how the experimental study was conducted, this study made the suggestion that students' interests should be developed at an early age. As a result, it appears that the research findings addressing attitudes toward physics laboratory experiments are inconsistent. After different modes of experimentation have been introduced and supported by guided inquiry-based learning, it is crucial to examine attitudes toward physics laboratory experiments. Additionally, the current study focused on preservice physics teachers', who will lay the groundwork for high-quality science instruction for children and students of all ages.

Students' positive attitudes towards physics in today's digital world can be increased with the use of technology-enhanced physics instruction environments (Kapici & Akcay, 2020). One technique to use ICT in studying physics laboratory experiments is to blend a virtual laboratory with a real laboratory (Darrah et al., 2014). Research on the different learning outcomes of blended laboratory experiments in physics has been inconsistent. For instance, a study on upper primary school students' attitudes towards science after completing hands-on, virtual, and blended laboratories by Kapici & Akcay (2020) found that the students had a more favorable attitude towards science. No differences in attitude change were found between hands-on, virtual, or blends of these laboratories, according to data based on the questionnaire, while descriptive data suggested that virtual laboratories were more successful for changing attitudes than hands-on laboratories. As was revealed through the interviews, there may be a relationship between this and students' overall, though small, preference for virtual laboratories over hands-on laboratories.

Additionally, a study employing conceptual tests in the field of microscopy and affective questionnaires examined the effects of combining the use of virtual laboratories and research laboratories on university students' attitudes, knowledge, and interest (Hurtado-Bermúdez & Romero-Abrio, 2020). The results demonstrated that students might benefit from combining virtual and real laboratories in order to enhance their learning beyond what either approach could offer alone. The authors claimed that blended experiments have the potential to be an important tool for achieving affective and performance-related gains. The research findings imply that technology-enhanced physics laboratories have emerged as a viable alternative to hands-on laboratories. However, their efficacy in fostering science learning may be affected by social and motivational variables, as well as how the course incorporates new technology (Corter et al., 2011). It was suggested to conduct additional research to further examine and improve the promising elements of the blended strategy.

For a variety of reasons, the learning outcome of attitude toward physics laboratory experiments was selected in order to examine the impact of blending virtual and real laboratory designs. On the one hand, the current study sought to investigate how PSPTs reacted to different laboratory designs, particularly technology-enhanced laboratories, which are relatively recent developments in the current research context. The second rationale was that studies have shown that students learn physics more effectively when they have a favorable attitude toward physics laboratory experiments. The third reason was because it has been determined that practical work and laboratory experiments are the most successful means to impact students' attitudes toward the subject, which in turn affects how well they perform (Basey et al., 2008). There are also assertions that the research on physics laboratory education has not adequately taken into account students' attitudes toward laboratory instruction and that further research is required in this area of study (Basey et al., 2008; Hofstein & Lunetta, 2004).

The benefits, interest, importance, desire to learn physics in the laboratory, anxiety in the laboratory, and facilities in the laboratory are all components of attitude towards the physics laboratory (Saputra et al., 2020). Many attitude scales have been developed to assess students' attitudes toward science. However, an adapted version of an attitude scale was employed in this study to examine pre-service teachers' attitudes about physics laboratories.

2.13. Inquiry-based learning

Many authors provide different definitions and explanations for inquiry-based learning. The definition include from formulating questions and making observations through conducting research to see what information has already been documented, designing methods for experiments, designing tools for data collection, gathering, analyzing, and interpreting data to illustrating potential explanations and establishing predictions for additional studies (NRC, 2005). The explanation reveals the various ways that a scientist investigates the natural world and the phenomena in it. According to NRC (2005), student inquiry can involve reading about scientific ideas and theories, posing questions, planning investigations, undertaking observations, employing tools for gathering and analyzing data, coming up with explanations, reviewing accepted theories and concepts in the context of empirical data, and reporting results. The explanations provided by the institutions are more or less similar in that inquiry is viewed as various ways of investigating the natural world, beginning with a problem and seeking to solve it before summarizing the results.

Different levels of inquiry-based learning for science classrooms are suggested. According to Banchi and Bell (2008), inquiry levels can be classified into four scales. The first level is confirmatory inquiry, in which the teacher first teaches a particular science topic and then develops procedures and questions that guide students through activities where the end result is already known. The second level is structured inquiry, in which the teacher provides the initial questions and a sequence of steps, and students are expected to develop interpretations of their findings by assessing and analyzing the evidence they have gathered. The third level is guided inquiry, in which the teacher offers research questions and students are given the responsibility for developing and implementing their own techniques to answer the questions posed, and then they are given the chance to communicate their findings. The fourth level is open inquiry, which offers students the chance to propose their own questions, design and carry out a planned technique, and present their results.

Schwab's level of inquiry approach in science teaching was presented by Imaduddin and Hidayah (2019) which has four levels, from 0 to 3, and is distinguished as open, guided, structured, and confirmatory inquiry, in descending order. Level 0 is the lowest stage of investigation, known as structured inquiry, in which the teacher retains authority over the source of the question, methods for gathering data, and interpreting results. At level 1, the teacher decides how to ask the questions and gather the data, and the students analyze the results. At level 2, the teacher sets the questions that must be answered, but the students are free to interpret the data and respond to the questions in any way they see appropriate. Levels 1 and 2 are classified as guided inquiry. In level 3, students control all aspects, such as asking questions, gathering data, and interpreting, and this is referred to as open inquiry. Scholars claimed that more research is required to understand which levels of inquiry can be used in science instruction and how (Almuntasheri et al., 2016; Bunterm et al., 2014). Although research appears to support the effectiveness of both open and guided inquiry-learning strategies, it is still debatable which one is more effective approach for teaching and learning in science classrooms (Sadeh & Zion, 2009). Some authors claim that open-inquiry learning boosts students' capacity for logical thinking and their levels of inquiry (Berg et al., 2003). On the other hand, proponents of the guided inquiry technique recommend its effectiveness in avoiding time waste and lowering student displeasure with unanticipated outcomes (Trautmann et al., 2004).

According to Baloyi (2017), strategies that support constructivist learning, conceptual understanding of physics concepts, and the development of abilities that motivate students to comprehend facets of NOS and scientific inquiry processes are all necessary components of effective physics instruction. Students should be asked leading questions during science instruction, and they should be guided and supported in their quest for knowledge.

2.13.1. Levels of inquiry-based learning

Physics education research revealed that conventional physics laboratory activities that do not allow students for active engagement and participation, where the teacher uses physical equipment and materials to demonstrate a physical phenomenon, failed to add to students' learning of physics (Etkina et al., 2002). These conventional physics laboratories are largely dependent on passive lecture demonstrations and recipe-based or expository laboratory activities dominated by the teacher. Recognizing the failures of conventional physics laboratories, many research-based methods have been developed to promote student learning in physics. In response to this, inquiry-based physics experimentation has been suggested, which is informed by a constructivist perspective.

Inquiry-based learning is an inductive process that can be implemented in a variety of laboratory classes and used to increase students' development of scientific skills and attitudes toward science instruction (Sujarittham et al., 2019). In guided inquiry-based learning, students are given a problem or a question and must plan how to solve an experimental problem or test a hypothesis. As a result, the students must devise their own investigation procedure in order to discover an undetermined outcome. Students are given the opportunity to think scientifically as a result, and through time they will learn new things and come to understand concepts, theories, and principles for themselves (Sujarittham et al., 2019; Banchi & Bell, 2008).

Inquiry-based learning is a method of teaching that enables students to participate actively in the process involving carrying out observations, formulating questions, designing investigations, assessing what is already understood regarding prior experimental evidence, gathering, analyzing, and interpreting data, suggesting answers, explaining, and reporting the results (Arslan, 2014). It is in contrast to instruction in which the students receive and record information, memorize facts and formulas, and verify laboratories presented by the teacher. When used in physics experimentation, inquiry-based learning enhances students' scientific inquiry skills, conceptual understanding, and attitude towards physics and experimentation activities in physics.

Though there are different arguments on the various levels of inquiry learning, recent articles suggest four scales of inquiry-based learning: open, guided, structured, and confirmatory (Arslan, 2014; Banchi & Bell, 2008). The authors claimed that the classification is based on whether the teacher prescribes the problem, the equipment and materials used, the procedure to be followed, and the solution or expected answer to the problem. In the confirmatory level of inquiry-based learning, the question, the method, and the solution are all stated clearly by the teacher. In structured inquiry-based learning, the question and the method are specified, whereas the solution to the problem is left to the students to investigate. In guided inquiry-based learning, the question is given to students, and then they are self-directed in terms of designing procedures in order to investigate the problem. In open inquiry-based learning, students are expected to design the whole process, from formulating their own questions to solving the problem.

The first two levels of inquiry-based learning, confirmatory and structured, are highly criticized because of their inadequacy in engaging students in their learning. These levels are described as cookbook laboratories, which are focused on recipe or expository types of experimentation. Guided inquiry and open inquiry, on the other hand, are more complex forms of learning because these levels require students to design their own experiments and procedures to follow (Arslan, 2014).

In the literature, there are also debates on the roles of guided and open inquiry approaches to learning. In guided inquiry learning, the teacher participates in or guides some phases of the inquiry cycle, such as offering the research question and assisting with the design of the investigation. Open inquiry, on the other hand, requires greater engagement from the students because they have the responsibility of coming up with their own investigation questions, planning an experiment, and coming to their own conclusions (Cairns, 2019; Arslan, 2014). It may lead to a problem of cognitive overload in students because they fail to possess the basic skills and knowledge needed for the whole process (Kirschner et al., 2006). In this study, guided inquiry learning is implemented with the appropriate guidance of the physics teacher educator, but it is difficult to employ open inquiry since students are not ready for this approach.

Even though inquiry-based laboratories have the potential to enhance students' high-level reasoning, analytical, and scientific inquiry skills, they haven't really taken off, with some physics laboratory courses still primarily being used as a venue for demonstrating physical principles from lecture courses (Meltzer & Otero, 2015). On the other hand, developing scientific concepts from real-world examples is a challenging process that requires exhausting tasks. Students require adequate time and space for interaction and thought on complicated and investigative activities. Blended learning to some extent addresses this issue, but it has seen limited implementation, most likely due to the challenging infrastructure resources, such as technology intensive classrooms, equipment and maintenance costs, and fully trained and committed staff (Bao & Koenig, 2019). These authors conducted a brief review of prior physics education studies to establish context for future work in improving deep learning and high-level reasoning skills for the twenty-first century. The authors stated that there is an urgent need to transform standalone laboratory courses into more inquiry-based designs, with one of their primary aims being to improve scientific reasoning skills when working within the constraints of the present education infrastructure. These laboratories should focus on improving knowledge as well as hands-on and mind-on practical skills such as problem modeling, designing and carrying out experiments, analyzing and interpreting data, drawing and evaluating findings, and effective communication.

2.13.2. Inquiry-based learning and PhET interactive simulations

Technology has become pervasive in enhancing and progressing science learning and teaching due to its ability to change teaching practices and learning processes. To meet the needs of the twenty-first century, one example is the use of virtual laboratories as an alternative to physical laboratories. PhET, developed by the University of Colorado and freely available on its website, https://phet.colorado.edu/, is an example of a virtual laboratory (Maulidah & Prima, 2018; Finkelstein et al., 2005). It was founded to enhance science teaching and learning around the world through the use of free interactive simulations (Banda & Nzabahimana, 2021). Over 50 physics simulations are available both offline and online, and they are designed to be highly engaging, interactive, and open learning environments with dynamic feedback for the user. In the simulations, physics principles are highly visual, physically accurate, and dynamically represented (Finkelstein et al., 2006).

According to the authors, PhET simulations improve science teaching and learning and are essential in the development of a platform rich in scientific and technological resources that allow students to engage in a variety of ways, such as deep conceptual understanding, scientific exploration, making connections to everyday life, and taking an active role in the learning experience (Banda & Nzabahimana, 2021). Other authors claimed that these simulations are authentic, interactive, and research-based, and that they provide numerous learning goals and meaningful learning (Perkins et al., 2014). The educational effectiveness of interactive simulations has been explained from a variety of theoretical perspectives. Constructivism, particularly social constructivism, is one of the theoretical perspectives that can explain the effectiveness of interactive simulations (Fan, 2015). In turn, inquiry-based learning is one of the research-based innovative instructional approaches that can make interactive simulations effective for a variety of learning goals.

The literature is replete with evidence that inquiry-based laboratory activities facilitate successful active learning as well as enhance cognitive development and positive attitudes toward science learning (McCreary et al., 2006; Oliver-Hoyo & Allen, 2005). Besides, Koballa & Glynn (2007) claimed that enjoyable and personally satisfying science learning experiences are likely to help promote favorable attitudes, increased motivation for science learning, and improved achievement. Instruction that places a strong emphasis on active learning and the application of science to everyday life are two strategies for influencing students' attitudes in a positive way. On the other hand, it has been argued that recipe-based laboratory experiments and activities are procedural in nature and unable to help students develop their critical thinking and reasoning abilities (Baloyi, 2017; Banchi & Bell, 2008).

2.14. The theoretical framework of the study

Theoretical perspectives are useful in research because they help us organize and communicate our thoughts and ideas to others. Educational researchers frequently use one or more theoretical perspectives when shaping research questions, planning and conducting research, and analyzing findings. In light of this, the current study has been informed by the theories of cognitive load and social constructivist learning. These theoretical underpinnings or perspectives were used to prepare instructional materials and implement the intervention.

2.14.1. The social constructivist learning theory

Though there is no consensus on different aspects, practical work has long had a distinguishing and fundamental role in the science curriculum. Many science educators and researchers have reported that many benefits can be obtained from helping students to actively participate in science laboratory activities. Laboratory experiments confer various advantages, such as enhancing laboratory skills, improving scientific knowledge, and developing an understanding of science concepts and theories (Shana & Abulibdeh, 2020; Schwichow et al., 2016; Fadzil & Saat, 2013). Additionally, it has been shown that practical work raises students' motivation and fosters a positive attitude for effective learning among students studying physics (Lee & Sulaiman, 2018), chemistry (Okam & Zakari, 2017), and biology (Hinneh, 2017). There are; however, contrasting views on the benefits of laboratory-based teaching and learning, as reported by Abrahams & Millar (2008). In addition, Etkina, et al. (2002) and Havlíček (2015) also noted that incorporating practical activities into the lesson thoughtlessly can be counterproductive. It implied that reformed instructional approaches should be used to benefit practical work and laboratory experiments in science education. Reforms in science education, such as the National Science Education Standards (NRC, 2000) and Hofstein and Lunetta (2004) have reported that inquiry-type laboratory activities have the potential to benefit students' learning in many dimensions. This does not necessarily imply that all laboratory activities that include inquiry improve student learning. For instance, Hofstein and Lunetta (2004) argued that inquiry in laboratory experiments alone is insufficient to help students acquire the expected learning. In addition, Driver (1995) pointed out that collaboration with a teacher and intervention are crucial if students' understandings are to be moved toward those of accepted science.

Though there are different inquiry levels in the teaching and learning process of science laboratories, the guided inquiry-based approach was selected in the present study. This was because the guided inquiry-based approach plays a fundamental role in shaping the inquiry experience by guiding students' thinking and activities to empower the students' desired learning from the investigation of the activity (NRC, 2005). It also extends to the fact that guided inquiry instruction allows the teacher to monitor the classroom ideas as they exist initially and as they develop.

The social constructivism learning theory places a strong emphasis on the social character of learning and the significance of the social environment. According to Pritchard and Woollard (2010), the social constructivist teacher encourages student reflection, peer interactions, and cognitive conflicts. Taking into account the students' preconceived notions, the constructivist teacher guides the activities to first reinforce and then expand upon them. As a result of the nature of practical work and the benefits it provides, a social constructivist theory of learning is required to guide the teaching and learning process. According to Shiland (1999), laboratory experiments and activities should take more time to complete, have fewer specific instructions, and have higher student accountability. Many documents on science education, including the National Science Education Standards (NSES), do not support a particular method for teaching practical work and laboratory experiments (NRC, 2000). However, the generalizations from laboratory activities were consistent with constructivism theory.

Many education research scholars and writers agree that conventional practices of teaching based on the 20th century transmissionism learning theory are not suitable to address 21st century challenges. Inquiry-based learning is commented on as one of the improved approaches to learning that is integral to creating a social constructivist classroom (Powell & Kalina, 2009). Of course, there is not a single accepted definition of what constitutes inquiry-based learning. This inconsistency in the definition of inquiry-based learning creates confusion regarding the roles of the teacher and students in the teaching and learning process. However, many authors linked inquiry-based learning directly to the social constructivism theory of learning and defined it under this umbrella. For example, Walker & Shore (2015) and Rapp (2005) related inquiry-based learning with social constructivist theory and defined inquiry-based learning as knowledge constructed through social interaction. Accordingly, different authors considered the role that the teacher plays during inquiry-based learning as the guide, the one who sets a rich and supportive social environment where students take responsibility for their learning and collaboratively work with their groups (Lazonder & Harmsen, 2016).

Many agree that the emergence of information and communication technology has brought tremendous opportunities to the educational context. More specifically, ICT has been an effective tool for enhancing teaching methodologies, improving learning quality and experiences, and increasing students' participation and motivation for their own learning (El Kharki et al., 2021).

According to Muller (2008), many educational researchers are keen to accept the conclusion that conventional teaching practices were ineffective, and reformed ones such as inquiry-based methods supported by constructivism theory of learning were advocated. The discussion in relation to social constructivist theory of learning, guided inquiry-based learning, cognitive learning theory, and the role of ICT in science education laboratory work helped the researcher develop the conceptual framework of the study and identify independent and dependent variables. It is also essential to discuss learning theories because they are used to determine how students learn best. Many attempts have been made in the literature to understand how learning occurs. As a result, social constructivism learning theory and cognitive load theories underpin and guide the current study.

For more than two centuries, people have been wondering how people learn. It was later imparted for the emergence of educational learning theories: behaviorism, cognitivism, and constructivism, after a long journey. Advocates of behaviorism focus on measurable and observable behaviors, and this notion informs the goal of education, instruction, the curriculum, and the roles of the teacher and students. Proponents of cognitivism, on the other hand, focus on how the mind receives, organizes, stores, and retrieves information when needed. Learning, in this view, is an internal process, as opposed to behaviorists, who saw learning as an externally observable and measurable behavior.

Constructivism, an extension of cognitivism, holds that students construct knowledge and build their representations actively as they experience the world rather than being passive recipients of information. In the context of education, it can be argued that we should not be ignorant of any of these theories. Instead, the benefits and drawbacks of each learning theory in connection to the ultimate goals of education should be critically examined when setting educational goals, designing curriculum and instruction, and recommending the roles of teachers and students. The expected learning outcomes should inform our reliance on the selected learning theory when it comes to physics education in particular and science education in general. For the reasons stated in the following section, social constructivism was chosen to inform current research in the preparation of instructional materials and the role of the teacher and pre-service physics teacher.

The social constructivist view of learning, in which context is very important, informed the preparation of instructional material and determined the roles of the teacher and students. According to this viewpoint, knowledge is developed within the context of one's own experiences through collaboration with others. That is to say, new ideas emerge from a combination of voices and are gradually interconnected to form a collaborative conclusion, in which knowledge is socially co-constructed (Chin, 2007). Vygotsky, cited in Kola (2017), asserts that social engagement, with an increased focus on dialogue and other forms of interaction, is an important aspect of promoting intellectual and cognitive development.

According to Pritchard & Woollard (2010), social constructivists argue that reality is not something that exists and can be discovered but rather that it is constructed through shared human social activity. In other words, meaning and understanding are constructed by an individual through social and cultural means. And learning is a social process that takes place when the individual is engaged in social activities. Though laboratory experimentation is reported to be essential in physics instruction, the type of implementation affects its effectiveness. That is, pre-service physics teachers will learn more effectively if the physics teacher educator recognizes their prior knowledge and provides them with as many opportunities for social interaction as possible. Many of them come to the classroom with preconceived ideas and would be able to resolve many of them during the interaction, and the physics teacher educator should modify instructional strategies based on their thoughts, experiences, and interests during the process.

2.14.2. Social constructivist learning in PhET simulations and inquiry-based learning

In the current study, there are a variety of ways in which social constructivism theory can be expressed in PhET simulations and guided inquiry-based activities. The first is that PhET simulations were designed using a constructivist approach (Finkelstein et al., 2006). When students have the opportunity to explore within interactive computer simulations, they build their understanding through the experience of utilizing and manipulating the PhET (Wieman & Perkins, 2006). Students may study physics ideas and phenomena that are invisible to the eye, such as electrons, and that cannot be directly observed, like electromagnetic fields. By making the invisible visible, PhET simulations help students learn (Wieman & Perkins, 2006). According to Finkelstein et al. (2006), PhET simulations take an interactive approach, use dynamic feedback, adopt a constructivist theory, and make explicit models or phenomena that are otherwise unavailable.

The second point is that many educational innovations, such as the inquiry-based approach, have incorporated the tenets of constructivist learning theory. According to Arslan (2014), inquiry incorporates social constructivist theories of knowledge formation and is supported by evidence. These include the fact that learning is an active process in which students construct meaning for themselves, that the meanings each student builds depend on their prior ideals, that the understandings they develop depend on their contexts, and that meanings are socially constructed, so that understanding is improved by engaging with ideas in collaboration with other students. The explanations demonstrate how the inquiry-based learning approach reflects social constructivist learning theory. Although there are various levels of inquiry, many authors have found that guided inquiry laboratories enhanced students' learning and retention (Irinoye et al., 2015), assisted them in fostering positive attitudes (Chatterjee et al., 2009), and helped them understand the nature of science (Thompson, 2007).As was already mentioned, inquiry learning works better when it is supported by guidance.

The importance of guiding in an inquiry-based learning environment can be attributed to the fact that the right kind of assistance can help students overcome the constraints of working memory and help them retain new information in long-term memory. When planning their teaching strategy and environments, teachers should take the cognitive learning theories into account. Additionally, certain cognitive learning theories concur with the idea that learning is improved if the loads placed on working memory are reduced. According to Kalyuga and Singh (2016), novice learners may experience cognitive overload when learning specific concepts or procedures as a result of this lack of explicit instruction. For instance, for students who have a high level of prior knowledge, detailed activities can reduce the learning outcome because the content requirements impede their ability to independently generate knowledge. Whereas these scaffolds are especially useful for learners with insufficient prior knowledge. These justifications might aid in maintaining the appropriate amount of prior knowledge and the type of teacher guidance. The subsection that follows discusses cognitive load theory and its importance for providing appropriate guidance for physics laboratory experimentation.

2.14.3. Cognitive load theory

Scholars claim that care should be taken in designing laboratory manuals in order to maximize learning by reducing extraneous load (Jarrett et al., 2010). Domin (2007) pointed out that working memory overload is an impediment to successful learning in laboratories because the task of sorting through the overabundance of information in cookbook laboratory instructional materials frequently places a heavy burden on the students' working memory. According to Jarrett et al.

(2010), the cognitive load theory (CLT) contends that while humans have practically unlimited long-term memory, their working memory is constrained and can often only handle four items at once. It can be divided into three categories: germane (caused by the type of instruction yet essential to the learning); extraneous (caused by the method of instruction and not related to the material that needs to be taught); and intrinsic (caused by the nature of the knowledge to be learned) (Paas et al., 2004).

According to research on CLT, instructional materials that are properly designed can help reduce irrelevant cognitive load (Jarrett et al., 2010). That is why this theory is selected to guide the present study since there will be information overload in preparing instructional materials for the intervention of treatments. The curriculum materials prepared for the intervention of the study will be kept from information overload and extraneous load by carefully preparing the materials guided by cognitive load theory.

It is claimed that the use of educational technology shouldn't be based on a single learning theory (Thomas, 2010). In order to tie together many elements and provide the psychological basis and theoretical framework, research regarding blended laboratory learning might be theoretically founded on a variety of well-established ideas, principles, and sources of literature. The social constructivist and cognitive load theories served as the foundation for the current investigation, regardless of the fact that they appeared to be at odds with one another. Some cognitive load theoriests state that allowing students to construct their own learning experiences will overburden their working memory, which will undermine learning (Kirschner et al., 2006). However, some constructivist researchers contend that constructivist strategies such as inquiry-based learning are consistent with the cognitive architecture of humans (Upu & Buhari, 2021; Hmelo-Silver et al., 2007). According to the authors, inquiry-based learning is consistent with human cognitive architecture since it offers dynamic guidance adaptation, based on the complexity of the learning task or the level of learner skill. Thus, constructivist approaches work well with human cognitive architecture because they allow for flexible adaptation of guidance, including scaffolding to reduce students' working memory load.

Complimentary nature of cognitive learning theory and constructivism learning theory may be supported by a number of pieces of evidence from the literature regarding laboratory teaching. The utilization of technology-enhanced laboratories to enhance inquiry is thought to be a developing concern in many countries (Husnaini & Chen, 2019). The application of technology, such as virtual simulations, may help students learn about inquiry-based learning and the constructive process of physics concepts in the laboratory (Jaakkola et al., 2011). The authors pointed out that using technology, such as virtual simulation, might minimize the amount of time required for inquiry, enhance the number of successful experiences, and lessen the burden of irrelevant factors on students. To put it another way, implementing technologically enhanced physics laboratories encourages students to engage in inquiry-based learning and the constructive process of conceptualization, demonstrating the complementary nature of the two theories. Additionally, by reducing irrelevant factors so that students' attention is focused on certain variables or phenomena that are relevant, simulation-based laboratories can reduce the cognitive load placed on students. As a result, it could be claimed that cognitive load theory and constructivism learning theory are complementary rather than mutually exclusive (Chen et al., 2012).

Recognizing the main cause of the dispute between the theories of cognitive load and constructivism is an alternate method for implementing constructivism while taking cognitive load theory into account. Divergent viewpoints on the need for instructional guidance throughout the learning process are the basic cause of the conflict between constructivism and theories of cognitive load. This will assist teachers in determining the optimal level of instructional guidance and enhance the level of student discussion. Teachers can provide scaffolds that reduce cognitive load by organizing tasks so that students focus on the aspects that are related to their learning objectives. In this study, particular emphasis will be placed on designing instructional materials that reduce unnecessary cognitive load in order to maximize the working memory resources that may be utilized to concentrate on relevant activities.

2.15. Summary of the literature review and research gaps

The literature review chapter in the present study has started with science education and its contribution to the all-round development of a country. It further extended the discussion of physics education, physics education research, and its topics. Science education in general, and physics education in particular, places a strong emphasis on practical work and laboratory experiments. Following this, the history, definitions, epistemological roles, and other issues of practical work and laboratory experiments were addressed. The different manipulative or learning environments of physics laboratory experiments were discussed in detail.

Because of the emergence of ICT, different alternatives to laboratory experiments have been introduced in the education system. Despite their role in physics education, there are continually conflicting research results on the effectiveness of the different laboratory learning environments. In this chapter, real, virtual, and blended modes of physics laboratory experimentation are discussed in detail. The recent research focus related to laboratory learning environments is a blended approach that combines real and virtual manipulatives in different combinations and sequences. Many of the studies in this area call for further research utilizing various methodologies, contexts, domains, levels of education, instructional approaches, and so on.

The course utilized in the current study was a laboratory course that consisted of topics in electricity and magnetism. As a result, the learning outcomes used to examine the effectiveness of the different laboratory learning environments are discussed in detail using the topic under consideration. Conceptual understanding, understanding of the nature of science, and attitude towards the physics laboratory are the learning outcomes used. These learning outcomes are discussed in detail, with a special focus on electricity and magnetism topics and pre-service physics teachers. The instructional strategy employed in this study was a guided inquiry-based approach, and it was discussed in relation to social constructivist learning and PhET interactive simulations.

As the literature on various physics laboratory experimentation modes was reviewed, different outcomes for students' physics learning were found (Wörner, 2022; Brinson, 2015). Apart from real experimentations, the emergence of ICT brought alternative platforms such as virtual and blended real and virtual experimentations in physics education. There is well-documented research output regarding the role of experimental activities in physics instruction. However, many scholars in physics education claim that inadequacy of equipment and materials and a lack of skilled manpower are the challenges to quality physics instruction, particularly in the African education system. In addition, it is difficult to represent very small and large physical systems, abstract concepts, and repeat the experiment when needed, which are also limitations of real physics experiments. Accordingly, alternative modes of physics experimentation are recommended by scholars in order to enhance students' learning in physics.

Virtual physics experimentation is one of the profits of ICT and is conducted using virtual materials on computer screens. However, this type of experimentation is criticized as it deprives students of the opportunity to practice physicality, which is the actual and active touch of concrete material. Research that compared real and virtual experiments reported continually debating results regarding benefits to student learning. Recent research has reported that blended physics experiments are beneficial in enhancing students' learning in physics. However, scholars suggest further research in different research designs, contexts, educational levels, domains, and learning aspects in physics.

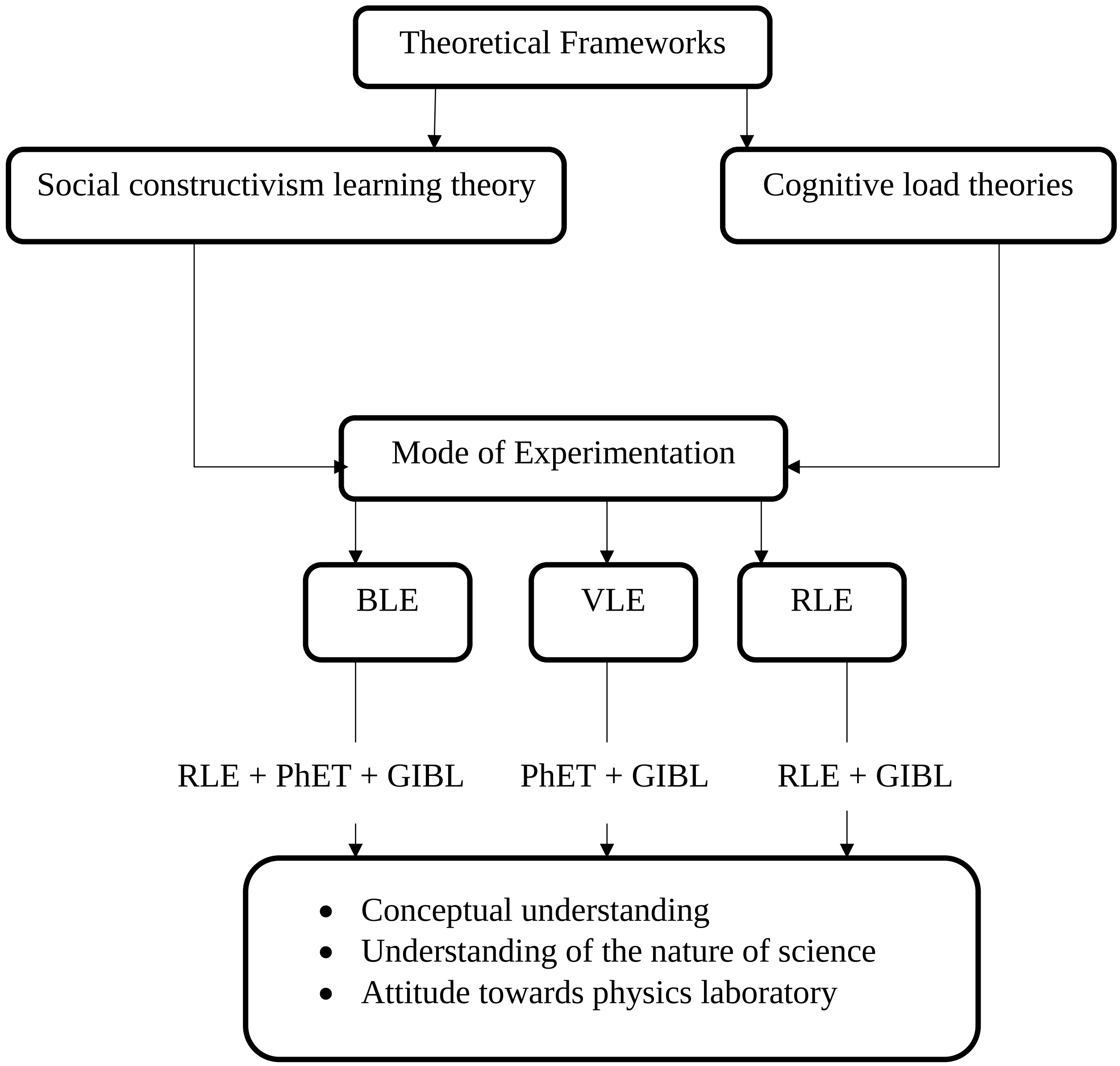
Furthermore, the vast majority of research studies are carried out in developed nations, and only a limited number of these types of studies are carried out in developing nations, including Ethiopia. Particularly in Ethiopia, technology-supported teaching is a recent phenomenon. Some scholars studied plasma-based instruction in Ethiopia and reported that it was not as effective as expected and planned. Thus, research should be carried out in order to provide insight about the efficacy of different modes of experimentation, particularly technology-supported instruction, before large-scale implementation. On the one hand, the results of examining the effectiveness of blending real and virtual physics laboratory experiments are inconclusive. On the other hand, the author of the present study was unable to locate a study that examined the impact of guided inquiry-based learning and blended physics experiments on the learning of pre-service physics instructors, particularly in Ethiopia. These realities serve as the impetus for the investigation of the topic. Thus, this study used a quasi-experimental approach to gather empirical data on the effectiveness of different experimentation methods, and it can offer an important insight into the ongoing discussions among academics who are studying the topic.

2.16. Conceptual Framework of the study

The conceptual framework of this research shows how the theoretical perspectives, independent variables (IV) and their levels, intervening variables (IVV), and dependent variables of the study are assumed to be related. Social constructivist learning and cognitive load theories served as the theoretical underpinnings for the current study. Social constructivist learning theory was adopted since it informs both the design of the interactive simulations in PhET and the instructional strategy of guided inquiry-based learning (GIBL). PhET simulations encourage and facilitate the active construction of knowledge through interaction between the student(s) and the content, rather than merely imparting knowledge. These simulations are also built on the design philosophy of the idea of cognitive load theory. According to this theory, teachers should employ different learning strategies and more effective cognitive methods to help students learn effectively. The cognitive load theory enables instructional designers to design educational materials that impose fewer loads on students' working memory, resulting in more effective learning.

The modes of experimentation, which included blended, virtual, and real physics laboratory experiments, served as the independent variable of the study. The guided inquiry-based approach and the type of manipulatives used, including real, interactive virtual simulations from PhET and a blend of the two, were the intervening variables. As can be seen from the conceptual framework, the guided inquiry-based approach was used to aid the blended mode of laboratory experimentation (BLE), which was carried out utilizing a blend of real and PhET virtual simulations. PhET interactive virtual simulations and a guided inquiry-based strategy were used to perform the virtual laboratory experimentation (VLE). The real mode of laboratory experimentation (RLE) was carried out with real or physical tools and materials, employing guided inquiry-based learning approaches. Lastly, using conceptual understanding, understanding of the nature of science, and attitude towards physics laboratories as the outcome variables, the efficacy of blended mode of physics laboratory experimentation was compared with the effectiveness of virtual and real experiments alone. These outcome variables were chosen from among the goals of physics laboratory education following a review of earlier studies. In an effort to illustrate relationships and the research process, the conceptual framework of the study maps out how various theoretical perspectives, independent variables, intervening variables, and dependent variables relate to draw coherent conclusions. Figure 2.1 below displays the conceptual framework for the study.

Figure 2.1:*Conceptual Framework of the Study*



CHAPTER 3: RESEARCH METHODOLOGY

Introduction

The purpose of the current study is to determine whether or not blended physics laboratory experiments may improve pre-service physics teachers' learning of electricity and magnetism when compared to virtual and real laboratory experiments. The chapter kicks off with a detailed discussion of philosophical perspectives originating from what people can know, what is possible to know, and how knowledge is generated, which would represent how the study looked at the research problem. The research methods were then described, including the target participants and how the treatment and comparison groups were selected, the research design adopted, the variables of the study, data gathering instruments and validity and reliability issues, data analysis and interpretation techniques, and ethical considerations.

3.1. Philosophical Perspectives

It is evident that our worldview informs us about educational philosophies. Again, educational philosophies inform the aim of education, which informs the goal of curriculum and instruction, and the roles of students and the teacher. Besides, ontological and epistemological perspectives inform a researcher on how to address a research problem or question to be answered. According to social science researchers, once a topic for a study is identified, the researcher must consider how to investigate the problem. The approach taken will be determined by how the researcher thinks about the problem and how the problem is investigated in order for the study's findings to be credible to the researcher, others in a similar discipline, and audiences. Though each researcher has his or her own perspective on reality and knowledge, ethics, and value systems, these perspectives inform the researchers' thinking, beliefs, and assumptions about a particular worldview known as a paradigm (Chilisa & Kawulich, 2012).

Philosophical perspectives on the nature of reality, both social and natural, ways of knowing that reality, and ethics and value systems all influence how a world view or paradigm is described. The paradigm chosen, in turn, influences the researcher's methodology, which is reflected in the questions asked and the use of appropriate approaches to systematic inquiry (Chini et al., 2012). Of course, there are misunderstandings when it comes to the terms paradigm and philosophical worldview. To represent a set of beliefs and values held by and guiding the practices of a community of scientists, the term philosophical worldview is synonymous with the term paradigm (Kuhn, 1970). As a result, the term paradigm is used to represent the philosophical worldview in this study. According to Mertens (2010), a paradigm is a way of viewing the world that is made up of philosophical assumptions that inform and direct thought and action. It is suggested that educational researchers select a research paradigm that is compatible with their beliefs about the nature of the reality with which they are dealing (Levers et al., 2006; Mills et al., 2006). This is because paradigms influence researcher's orientation, methodological approaches in selecting a research design and methods, and how they critique each other's work (Tadesse, 2015).

There are several concerns that must be addressed in order to handle the challenges of providing high-quality physics education, which demands a wide range of responses to any potential research questions. It is apparent that not all research problems are of fundamental importance, and not all methodologies are inherently appropriate. In the end, it is the researcher who decides which question is significant and what methodology is appropriate, and such decisions are undoubtedly impacted by a variety of factors, such as personal experience, belief system, and the social environment the researcher lives in, among others. In the current study, the researcher considered the efficacy of blended mode physics laboratory experimentation on the physics learning of college of teacher education students as a single ontological existence that could be known with some degree of certainty. The learning outcomes that were used to examine the efficacy of the intervention were conceptual understanding, understanding of the nature of science, and attitude toward physics laboratory. In order to obtain a complete picture of the intervention, it was important to take into account the degree to which the intervention helped students understand the lessons learned, the opinions of students, teachers, and laboratory technicians regarding the intervention, as well as the overall quality of the intervention. This reality is dynamic and subject to change at any time, for instance, when participants have sufficient technological literacy.

It is not reasonable to claim that the researcher was not completely objective or value-free in choosing the research topic and methodology. The researcher used a range of methods for planning, conducting data gathering, analyzing, and interpreting the data, which appears to have resulted in the integration of many paradigms. As a result, it appears that the positivism of scientific methods as well as the relativism of social theories both have drawbacks for the current research. The quantitative-qualitative dichotomy cannot be used to solve any of the aforementioned activities; rather, pragmatic efforts that allow for the use of many ways simultaneously, such as mixed methods and mixed theories, should be taken.

Because of the growing interest in overcoming the inadequacies of either post-positivist or constructivist research paradigms in educational research, pragmatism has emerged as an alternative paradigm for mixed methods research. According to Tadesse (2015), Feilzer (2010), the pragmatism research paradigm emphasizes practical thinking and workability. It seeks to address research problems and questions, regardless of metaphysical concerns. It is guided by the principle of *what works best*, but only after careful observation and reasoning. As a result, the pragmatist research paradigm is well suited to integrating quantitative and qualitative research methods (Dawadi et al., 2021; Tadesse, 2015; Morgan, 2014). To summarize, the pragmatist research paradigm asserts the existence of a single ontological reality that can be understood in a variety of ways by different observers. In the current study, the effects of blended physics laboratory experimentation on single ontological existence can be understood in a variety of ways using both quantitative and qualitative data gathered from various study participants. As a result, the pragmatist research paradigm informs this study.

Pragmatism is built on the assumption that researchers should use the philosophical and methodological approaches that are most suitable for the particular research problem they are examining (Tashakkori et al., 1998). To this end, pragmatist research paradigm supports the use of mixed methods or multiple methods to collect and analyze data and report results. According to Tadesse (2015), the *what works is best* notion of pragmatism makes it suitable for use when conducting mixed methods research, which incorporates both quantitative and qualitative assumptions into a single research project. The pragmatist paradigm places an emphasis on outcomes, such as actions and situations of inquiry, and selects methods, procedures, and techniques based primarily on their applicability and practicability (Mertens, 2010; Johnson et al., 2007). Educational research scholars claim that the focus of the pragmatist paradigm in education research is more on the concerns of the research and the questions posed than on the methods employed (Teddlie & Tashakkori, 2009). In relation to rhetoric style, the pragmatist paradigm allows both formal and informal rhetoric schemes (Creswell & Clark, 2018).

Informed by the pragmatic research paradigm, which disregards the idea of value-free inquiry and recognizes that the researcher may employ a range of methods to address the problem in question. This will help the researcher at every stage of the research process, from formulating the research questions through gathering, analyzing and interpreting the data to writing the report. To answer the specific research questions posed, the researcher utilized a variety of data gathering methods, both qualitative and quantitative.

3.2. Research Methods

This section of the chapter presents the justifications for the suitability and appropriateness of the mixed methods research employed in this study. Due to the supportive role that the qualitative data plays in the current study, which was predominantly based on quantitative data, the embedded approach of the mixed methods design was adopted. An integration of qualitative methods from the constructivist paradigm and quantitative methods from the post-positivist paradigm was made. However, the quantitative strand was dominant over the qualitative one, so the less weighted strand was nested inside the more weighted one, which explains the quantitative results (Creswell & Clark, 2018).

The first part of the research question focused on the causal relationship between the independent variable, the modes of physics laboratory experimentation (blended, virtual, and real), and the dependent variables, the outcome variables measured (understanding of the nature of science, conceptual understanding, and attitude towards physics laboratories). The research subjects were second year physics linear diploma pre-service teachers taken as intact classes in their natural setting in three CTEs. The second part of the research question focused on the intervention scenario, how the participants perceived it, and their suggestions for improvement. Specifically, the study explored the perceptions of pre-service physics teachers, laboratory technicians, and physics teacher educators about the overall intervention process. This part was addressed using qualitative data, which included semi-structured interviews and observations of laboratory sessions. These two different approaches to inquiry, which were informed by the pragmatic paradigm, were employed to address the research questions raised by the study.

Quantitative research methods were employed to investigate the efficacy of different modes of physics experimentation on pre-service physics teachers' learning. Though the dominant data were obtained through a quantitative research approach in order to examine causal relationships, a qualitative research approach was also employed in order to explore the degree of implementation of the interventions and the perceptions of the teacher educators and pre-service physics teachers so that a full picture of the issue under study would be acquired. The differences in mean scores and their significance level should be studied using a quantitative research approach, whereas the degree of implementation of the interventions, or to get a better understanding of how the intervention works, and the perceptions of teacher educators and pre-service physics teachers should be studied using a qualitative research approach. As a result, the current study employed mixed methods research to address the first three research questions (1, 2, and 3), which required quantitative research methods, and the fourth research question, which could be addressed by qualitative research methods.

3.3. Research Design

As was already said, the first part of the study focused on the effects of the independent variable on the dependent variables, while the second section of the research focused on the quality of the intervention. In other words, the purpose of the current study was to learn more about how the intervention works while simultaneously examining the effects of the blended mode of physics laboratory experimentation. When these two approaches were combined, the current study was positioned inside the pragmatic paradigm, which supported the mixed-methods quasi-experimental design. An embedded mixed-methods design was adopted, where the quantitative data was larger and the qualitative data served as support. The tools for gathering both quantitative and qualitative data were used simultaneously. The quantitative data was dominant, while the qualitative data was embedded. The two sets of data were integrated during the analysis phase. Hence, the current study used a concurrent embedded mixed methods research design.

The pre-service physics educators who took part in the treatment and comparison groups were arranged in CTEs in their regular intact classrooms. The comparison and treatment groups were selected using simple random sampling, but there was no randomization of participants to each of the groups. To put it another way, the participants in the study were not evenly split between the comparison and treatment groups. The research design is presented symbolically in Table 3.1, with the abbreviations BEG standing for blended experiment group, VEG for virtual experiment group, and REG for real experiment group.

Table 3.1 *Schematic illustration of the research design*

Group	Mode of experimentation	Participant	Pretest	Intervention	Posttest
Treatment Group 1	BEG	NR=16	O1	X1	O2
Treatment Group 2	VEG	NR=26	O1	X2	O2
Comparison Group	REG	NR=21	O1	-	O2

Note: BEG represents blended experiment group; VEG represents virtual experiment group; REG represents real experiment group

Table 3.1 above depicts that treatment group one was intervened with blended physics experimentation through guided inquiry-based learning in such a way that virtual and real combinations were employed for each activity. Treatment group two was intervened with virtual physics experimentation through guided inquiry-based learning. And the comparison group received real experimentation through guided inquiry-based learning. In this study, NR represents non-randomization of pre-service physics teachers; O1 represents pretests offered for comparison and treatment groups before the intervention; and O2 represents posttests offered for comparison and treatment groups after the intervention. The pretest benefits the researcher since it allows for analysis differences that may initially exist between comparison and treatment groups so that appropriate statistics can be employed for analysis and interpretation of the data. The posttest was used at the end of the intervention for the mean comparison of dependent variables among treatment groups. From the above explanation, the current study was conducted in the natural setting of CTEs, where conducting a true experiment was not possible. As a result, a quasi-experimental, non-equivalent comparison group's pretest-posttest research design was employed in three groups (two treatment groups and one comparison group).

The intervention procedure consists of an initial visit to CTEs, followed by orientation, training, and the administration of a pretest, after which by intervention, laboratory session observation, and the administration of a posttest. The research lasted 12 weeks, from January 11 to April 2, 2021. The physics laboratory course comprised two two-hour contact hours per week. The pretest and posttest data were collected during the first and last two weeks, respectively. Laboratory session observations were made throughout the sixth and seventh weeks of instruction, while a semistructured interview was conducted during the final week of the study period. Physics teachers delivered the pretest and posttest, while the researcher conducted the semistructured interview.

3.4. Research Setting and Participants

The ultimate purpose of this study was examine the relative efficacy of the three modes of physics laboratory experiments, namely blended, virtual, and real, for overall physics learning. It included

63 second-year pre-service physics teachers who were enrolled in the laboratory course that was used as intervention material at three CTEs in Ethiopia's Amhara Region. The participants were regarded as having a number of characteristics in common, including educational background, age, instructional strategy, comparable experience of physics teacher educators, and prior understanding of physics themes among pre-service physics teachers. The CTEs were responsible for preparing pre-service diploma teachers for the primary school first cycle (grades 1–4) and second cycle (grades 5 –8). All of these CTEs followed the same three-year teacher training curriculum, which is in accordance with the Ministry of Education, despite the many changes in the modalities or versions of teacher preparation programs at colleges (MOE, 2003). The two modes of teacher preparation curriculum were cluster and linear. The former is intended to prepare teachers for the first cycle of primary schools (1–4), and the latter is intended to prepare teachers for the second cycle of primary schools (5–8). English was used to teach the linear diploma program as the language of instruction, while Amharic, Awigne, Himtana, and Afaan Oromoo served as the language of instruction for the cluster program in some CTEs.

Based on an earlier survey of the colleges, three of the ten Amhara region CTEs were selected for the study. Out of the ten CTEs, only five of them were offering a linear physics diploma program in physics in the Amhara region. The researcher visited and collected preliminary data before deciding the type of intervention employed in each college. This is because CTEs selected for blended, virtual, and real physics experimentation should have the necessary facilities and materials in order to minimize some of the confounding variables that could affect the research results. The criteria for selection were availability of laboratory materials, a trained physics laboratory technician, a qualified physics teacher educator, the presence of appropriate batches of students taking the targeted laboratory course, and ease of accessibility. As far as the laboratory course was concerned, background checks assured that these colleges were of similar status. The same physics curriculum was implemented in all the three CTEs. Even though the 10+3 diploma program allows the admission of pre-service physics teachers who completed grades 10 and 12, all of the trainees in these 3 CTES were grade 12 completes.

The physics linear diploma curriculum is one of the linear curricula implemented for pre-service teachers in CTEs. The curriculum has 13 major courses, of which 3 are laboratory courses; 5 mathematics courses offered as minor courses; 1 chemistry and 1 biology supportive course; 8 common courses; 4 practicum courses; and 13 professional courses. The curriculum for the physics diploma program has been organized in such a way that the course is delivered with laboratory work in a semester. This is the approach taken to address practical work and laboratory experiments in physics courses. Otherwise, the physics curriculum makes no explicit mention of practical work or laboratory experiments. With the exception of a few passionate physics teacher educators, the researcher's experience has revealed that practical work and laboratory experiments are rarely conducted in other physics courses at CTEs. According to Alemu et al. (2021), the learning objectives for the physics courses offered in CTEs focus on physical laws, models, and theories rather than practical applications and every-day phenomena. The authors also noted that the emphasis on experimental courses was above what PSPTs were required to demonstrate. For instance, they were expected to learn how to use electrical measuring devices and estimate experiment uncertainty.

The study was carried out during the course schedule in the first semester of the 2020–2021 school year (January–March). Participants in the research were first-year students in 2019/2020, around March. The program was interrupted for more than a semester as a consequence of the COVID-19 pandemic lockdown. During the months of October through December, these groups finished their first-year, second-semester course. Beginning in January, these students registered for the first semester of their second-year courses.

The researcher initially planned to conduct the study at all five colleges, with four experimental groups and one comparison group. However, the semester program became too tight to compensate for the schedule missed because of the lockdown due to the pandemic. It had become difficult for the researcher to undertake a follow-up in the three phases of the research, namely, before, during, and after intervention. That is why the researcher decided to work only on three CTEs, though it was initially intended to replicate the intervention in the blended approach. An attempt was made to reach a valid conclusion using different sources of data.

Experimental Physics II (Phys 211), a laboratory course that included electricity and magnetism experiments, was used as the intervention course for the current investigation. This is because the study focused on the effectiveness of different modes of physics laboratory experimentation. Though there were slight deviations in the laboratory activities that CTEs use for the laboratory course under investigation, discussions were held with physics teacher educators and laboratory technicians to use the same activities based on the curriculum framework of the ministry of education. The physics laboratory course had 10 laboratory sessions indicated in the manual, consisting of electricity and magnetism topics. The experiments in the laboratory course covered a variety of topics, including charging methods, measuring current and voltage, charging and discharging a capacitor, factors affecting conductor resistance, series and parallel resistor combinations, Ohm's law, electromotive force and internal resistance, magnets and electromagnets, the magnetic field of a straight current-carrying wire, and electromagnetic induction. With the exception of charging and discharging a capacitor, all of these experiments have been completed during the intervention period of one semester. The treatment and comparison groups completed the nine laboratory activities in a similar manner, except for the mode of experimentation.

Table 3.2 *Physics laboratory experiments and their simulation alternatives for the study*

№	Title	PhET simulation	Topic
1	Charging methods	*Balloons and Static Electricity*	https://phet.colorado.edu/en/simulations/balloons-and-static-electricity
2	Measuring Current and Voltage	*Circuit Construction Kit: DC*	https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc
3	Ohm's Law	*Ohm's Law*	https://phet.colorado.edu/en/simulations/ohms-law
4	Factors affecting resistance of a wire	*Resistance in a Wire*	https://phet.colorado.edu/en/simulations/resistance-in-a-wire
5	Resistors in series and in parallel	*Circuit Construction Kit: DC-Virtual Lab*	https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc-virtual-lab
6	Electromotive force and internal resistance	*Circuit Construction Kit: DC-Virtual Lab*	https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc-virtual-lab
7	Magnetic field of a wire	*Magnets and Electromagnets*	phet.colorado.edu/en/simulation/magnets-and-electromagnets
8	Electromagnets	*Magnets and Electromagnets*	phet.colorado.edu/en/simulation/magnets-and-electromagnets
9	Electromagnetic Induction	*Faraday's Law*	https://phet.colorado.edu/en/simulations/faradays-law

Note: The full title of experiment number 7 reads as determination of the direction of the magnetic field of a straight current carrying wire using compass needle

Table 3.2 lists the titles of the nine laboratory experiments relating to electricity and magnetism that were performed in this research. The real and virtual versions were the two different types of manipulatives used in this investigation. The real manipulatives are those physical or concrete materials indicated in the laboratory manual to perform the laboratory activity. These manipulatives were employed with the blended experiment group, one of the treatment groups, as well as the real experiment group, which served as a comparison group. Physics Education Technology (PhET) interactive simulations were used for the virtual laboratory and blended laboratory groups. Offline PhET interactive simulations for which the corresponding real experiments can be conducted in all three colleges were selected. Fortunately, all of the physics laboratory technicians were trained with Physics Education Technology (PhET) software and applications. In colleges, laboratory technicians were often in charge of teaching laboratory courses, whereas teacher educators were responsible for evaluating physics pre-service teachers. Second, physics teacher educators and laboratory technicians faced challenges as a result of the intervention's necessity for active follow-up and encouragement of students' investigations throughout. Third, the impact of COVID-19 was also considerable. The directives by the government and ministry of education limited physical distance and contact.

There was also a shortage of time in the regular schedule to compensate for the academic time lost during the school closure. In order to overcome this problem, the researcher held detailed discussions and negotiations with the physics laboratory technicians and physics teacher educator about the purpose of the intervention in particular and the research in general. The majority of these challenges occurred at the start of the intervention and were eventually resolved through ongoing in-person and telephone discussions as well as other methods of communication. Training was given about the PhET simulations and guided inquiry-based learning of laboratory courses. Besides, observation was undertaken to see whether the implementation of the intervention was as planned. There was also close communication with the implementers via mobile and e-mail to facilitate the implementation of the intervention.

The selection of second year pre-service physics teachers was purposive because of three main reasons: First, the participants completed the measurement and mechanics-focused first laboratory course, where they learned the fundamental safety rules for laboratories as well as practice guidelines for writing reports. Second, there was only one section of third-year pre-service physics teachers at one college since the linear program was discontinued a year in advance. Thirdly, the researcher suspected that there will not be 2020/2021 entry pre-service physics teachers because of frequent changes in the modality training. Due of the COVID-19 pandemic, schools were forced to close, and there were no high school graduates enrolled in programs for first-year pre-service physics teachers. Because of changes in CTE curriculum rather than an unforeseen pandemic outbreak, the researcher was suspicious of the program's discontinuity.

Before implementing the intervention, an attempt was made to see the laboratory materials used in each study site. Though the CTEs use the same curriculum prepared by the ministry of education, slight differences were observed in preparing laboratory materials across the colleges visited. For the purpose of the study, the researcher held discussions with course instructors and laboratory technicians to complete the common practical activities and the rest will be covered at the end of administering the posttest.

3.5. Variables of the Study

One of the goals of an experimental research approach is to demonstrate whether changes in one variable directly affect changes in another, establishing a cause-and-effect relationship between the two variables. This approach uses two basic variables that are categorized as independent and dependent variables. The variable being tested for its effect on the dependent variable (DV) is the independent variable (IV). The researcher has tested whether changes in the IV have an effect on the DV by changing the IV and suggests that the IV is the reason for the change. The mode of the laboratory experimentation was the independent variable, whereas the different modes (real, virtual, and blended) of experimentation were the levels of the independent variable. The outcome that is measured is the dependent variable. It is what the researcher anticipates to be the result of altering the IV and is thus regarded as the effect. The pre-service physics teachers' learning, namely their conceptual understanding, understanding of the nature of science, and attitude toward physics laboratories on concepts of electricity and magnetism, were the dependent variables. The type of instructional strategy used for practical work and laboratory experiments has an effect on how well students learn physics. Thus, in order to reduce instructional strategy variations as a confounding variable, the different types of physics laboratory experiments for the participants of the treatment and comparison groups were facilitated using guided inquiry-based teaching methods.

First and most importantly, carrying out experiments enhances conceptual understanding in physics education. Second, while it only makes up one part of scientific literacy, conceptual understanding is one of the most crucial learning goals in science education. It is one of the most often assessed outcome variables in empirical studies in the field of educational research in general due to its marvelous relevance (Wörner et al., 2022). This is because conceptual understanding is so crucial in physics learning that many researchers attribute failure and success in physics to a lack of proper conceptual understanding and a gain of conceptual understanding, respectively (Phanphech et al., 2019; Kola, 2017).

As was noted previously in this section, understanding the nature of science was the other dependent variable utilized to determine the effectiveness of various physics laboratory experimentation modes. This is due to the fact that the nature of science (NOS) is an essential part of scientific literacy that boosts students' understanding of scientific concepts and empowers them to make wise judgments about personally and socially relevant scientific issues (McComas, 2013). The nature of scientific knowledge should be accurately understood by all science educators and everyone involved in science teaching and learning. That is why understanding of the nature of science is one of the goals of science education in general and physics laboratory education in particular (Akani, 2015; NRC, 2007). Laboratory experiments and activities help students better understand the nature of science. In the literature, there are different forms of questionnaires (closed, open, and mixed) suggested to measure learners views of the nature of science. A close review of the literature based on the development and validation of each of the instruments was undertaken to adapt it for this study. As a result, a closed-ended questionnaire followed by an open-ended questionnaire to investigate views of the nature of science were administered to pre-service physics teachers.

Attitude towards the physics laboratory was another dependent variable or learning outcome of the current study. Since the curriculum material was the laboratory course, the attitude towards physics laboratory scale was selected and used rather than the physics attitude scale. It is well recognized that there is a pressing need to boost the number of students pursuing science subjects, including physics, in many countries. The teaching of physics faces challenges, such as low student performance and unfavorable attitudes toward the subject, despite the necessity of physics for development. The process of explaining and understanding abstract physics concepts may be challenging for both students and teachers. The research on students' attitudes toward physics laboratory experiments remains in its early phases, despite the fact that many academics have already studied attitudes toward physics. In order to fully understand what happened in the laboratory, researchers can benefit from having a better grasp of students' attitudes about their physics laboratory experiments as well as the different modes of physics laboratory experiments. In order to gather affective characteristics of participants, a 5-scale attitude measure for the physics laboratory was adapted and used for this study. As a result, 34 questionnaire items were administered before and after the intervention to assess the attitude towards the physics laboratory of a pre-service physics teacher.

3.6. Data Gathering Instruments

Data were gathered for the current study using both quantitative and qualitative instruments. The quantitative data gathering instruments of the study were the conceptual understanding test, the understanding of the nature of science questionnaire, and the attitude towards laboratory questionnaire. In regard to how the dependent variables have been measured, conceptual understanding was assessed using adapted standardized tests on the concepts of electricity and magnetism in accordance with the experiment activities of the laboratory course utilized in the intervention. Understanding of the nature of science has been measured using adapted qualitative and quantitative data gathering instruments. In the quantitative part, there were 14 items on the 5-point Likert scale that ranged from strongly agreeing to strongly disagreeing. The qualitative part included six open-ended questions that required participants to provide written responses about how they perceived various aspects of the nature of science. The participants' attitude toward the physics laboratory has been measured using a 5-point Likert-type questionnaire modified from prior studies in order to examine how much of a negative or positive feeling they had before and after the intervention.

The instruments for gathering qualitative data for the current study were semi-structured interviews and laboratory session observation checklists. In order to examine the efficacy of the different modes of experimentation, semi-structured interviews and observation checklists helped identify participant opinions and the quality of the intervention, which supported the cause-and-effect relationship found from quantitative data. For this reason, observations of the laboratory session on the selected experiment activity and opinions from teachers and students regarding the mode of experimentation used and intervention quality were collected. The different methods for gathering data employed in the current study were discussed in detail in the following subsections.

3.6.1. Conceptual understanding test

The achievements of pre-service physics teachers provide evidence of their conceptual understanding, which in turn affects learning. For several physics topics, including mechanics, electricity and magnetism, and others, earlier researchers developed a number of instruments for assessing students' understanding of physics concepts. The topics of the present study were electricity and magnetism topics from the laboratory course offered for the linear physics diploma program. There are many assessment instruments available for examining how well students understand the concepts of electricity and magnetism. These include the Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney et al., 2001), the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) (Engelhardt & Beichner, 2004), and the Brief Electricity and Magnetism Assessment (BEMA) (Ding et al., 2006). It was difficult to obtain one particular standardized test that addressed the topics of the current study.

These tools were recommended by PhysPort, which was established by the American Association of Physics Teachers in partnership with Kansas State University, despite the criticisms that have been raised about various test types by various academics. The test items that best matched the topics of the present study were selected by the researcher. Then, after checking validity and reliability, pilot tests were conducted, and finally, 32 conceptual test items were used for the actual study. A letter of permission was received from Phys.org so that the researcher was allowed to sign in and download different assessment tools related to electricity and magnetism topics. The Kuder-Richardson reliability of the conceptual understanding test was found to be 0.810, which is acceptable.

3.6.2. Understanding of the nature of science questionnaire

In studies on the nature of science, assessing students' and teachers' views on the nature of science remains an ongoing issue. In several of these works, the nature of the science views of students and science teachers were investigated using standardized paper-and-pencil instruments that included forced-choice items like agree/disagree, Likert-type scales, and multiple-choice items (Lederman et al., 2002). These instruments were criticized from different perspectives, such as their validity and the developers' biases. Open-ended forms for views on the nature of science have been developed and validated by scholars in order to address these inadequacies. These types of instruments were also criticized because of their difficulty in analysis. As a result, it would be good to use both forms of instruments in a study to replace the weakness of one form with the strength of the other.

There are many instruments readily available to investigate various aspects of the views of the participants about the nature of science. Most of these instruments, which range from forced-choice Likert scales to open-ended questions, are made to be subject-specific rather than general in nature. Findlay and Souter (2008) examined a variety of tools to determine viewpoints on the nature of science. The authors pointed out that using items with Likert scales along with written justifications for responses would help reveal more about the views of the learners. Rich data can be collected using the open-ended response format, however, administering each VNOS would take roughly an hour. In addition, it is advised that a follow-up interview be conducted after responding to the questions; however, the administration time and the required follow-up interviews make VNOS excessively time-consuming.

The data collection instrument for this study was a 14-item Views of the Nature of Science (VNOS) questionnaire, which was adapted from McComas et al. (1998) and Findlay & Souter (2008). Additionally, six open-ended questions that were modified from literature (Miller et al., 2010; Liang et al., 2008) were used to collect views from PSPTs on NOS components. The open-ended items served as a posttest, whereas the closed-ended items were given both before and after the intervention. After these items were translated from English to Amharic, two colleagues—one a PhD candidate from the Department of Science and Mathematics Education and the other an English language lecturer in a teacher education college, looked into the validity of the translations. The reliability of the quantitative questionnaires was examined using Cronbach's alpha, and it has been found to be 0.708, which is within the acceptable range of values. The quantitative surveys were given out both before and after the intervention. All participants were once again requested to write on six selected NOS aspects after the intervention to support the quantitative findings.

3.6.3. Attitude towards physics laboratory questionnaire

For a variety of reasons, the learning outcome of attitude toward laboratories was selected in order to examine the efficacy of blending real and virtual laboratory experiments. Besides, the current study aimed to understand how PSPTs reacted to different laboratory environments, specifically technology-enhanced laboratories, which are relatively recent additions to the education system in the context of the current study. The second explanation was that it has been revealed that developing positive attitudes towards physics (Veloo et al., 2015) and laboratory experiments (Saputra et al., 2020) results in higher learning outcomes. That is, the physics laboratory experiments may be used to inspire students to study physics and be successful in their studies. The third reason was that laboratory experiments have been found to be the most successful means for influencing students' attitudes toward physics, which in turn impacts achievement (Basey et al., 2008). There are also assertions that the research on physics laboratory education has not adequately taken into account students' views toward laboratory classes and that further studies are required in this field (Basey et al., 2008; Hofstein & Lunetta, 2004).

An adapted 5-scale Likert-type attitude toward physics laboratory questionnaire was used to gather participant affective characteristics (Yesilyurt, 2004) and administered to gather participant affective characteristics. This scale was chosen because it is broad and addresses the three experimentation modes for pre-service physics teachers that were the subject of this study. Other scoring scales combine physics lessons with laboratory experiments (Kaya & Boyuk, 2011), while others place an emphasis on real or hands-on laboratory experiments and the availability of equipment (Saputra et al., 2020). As a result, all 34 items of the questionnaire were administered to assess attitudes towards the laboratory both before and after the intervention. These items were presented to participants side by side with the original, which was in English, and in the local language, Amharic. The items were developed to determine pre-service teachers’ attitudes regarding physics laboratory experiments. One of the reasons these instruments were used for the current study was that they were designed for pre-service teachers. The reliability of the attitude test questionnaire was determined using Cronbach's alpha, and an acceptable value of 0.765 was obtained.

As mentioned in the earlier sections of this study, a physics laboratory attitude questionnaire with 34 items was administered to PSPTs in the comparison and treatment groups in order to determine their attitudes before and after the intervention. In the questionnaire, 17 items were stated positively and 17 negatively. In order to make the analysis and interpretation more clear, these scores were recorded after transforming negative values into positive values.

3.6.4. Semi-structured interview

The interviews were conducted with two participants from each of the achievement groups (low, medium, and high) based on cumulative grade point average (CGPA), for a total of six from each study group. As a result, eighteen pre-service physics teachers were interviewed from two treatment groups and one comparison group about their perceptions and experiences with the mode of laboratory experimentation implemented. These semi-structured questions centered on how pre-service physics teachers perceived the physics laboratory intervention, which could be blended, entirely virtual, or real. Six interview questions were developed for the semi-structured interview by taking earlier research into account, particularly Hamed & Aljanazrah (2020), Kapici, et al. (2020), and Hinkhouse (2013). Participants in the study were questioned about how the experiment was different from the previous one, as well as about its advantages and disadvantages, individual preferences, degree of engagement, how it helped their understanding of the concept, and comments for further improvement. As part of the study, physics teachers and lab technicians were also interviewed with three questions about the differences between the new and old modes of laboratory experiments, their advantages and disadvantages, and the lessons learned for future development.

This qualitative data was primarily used to supplement the quantitative data in examining the efficacy of employing different modes of physics laboratory experimentation. For the blended, virtual, and real laboratory groups, a semi-structured interview was conducted with parallel but distinct questions about the modes of experimentation. It was conducted at the end of the semester, after the posttest had been completed by the participants. The interview with one PSPT participant took no more than 30 minutes to complete.

The researcher took notes as the participants responded to the specific questions posed. Moreover, interviews were carried out to find out what pre-service physics teachers, physics teachers, and laboratory technicians thought about the type of experimentation used in the laboratory. This information provided the researcher with a comprehensive picture of pre-service physics teachers' opinions on blended, virtual, and real laboratory learning environments.

3.6.5. Laboratory session observation

The treatment and comparison groups were observed while they were at work during selected laboratory sessions in different stages: beginning, intermediate, and final. Laboratory sessions with the same activity were selected for observation. This was designed to give the researcher the chance to observe whether pre-service physics teachers, the implementer teacher educator, and laboratory technicians in the comparison and treatment groups were actually engaged in the process. The laboratory session observations obtained from the different stages of the intervention process were qualitative data. The observation data were analyzed in order to triangulate and clarify the information obtained from quantitative data about the treatments. This would provide insights into the degree of implementation of the interventions.

The main objective of the observation checklist was to explore how the physics pre-service teachers conducted the laboratory experiments from the laboratory course that served as intervention material. This assessment rubric was developed by consulting the literature, especially the performance assessment of a physics laboratory experiment (Mubarok, et al., 2018) and the physics practical skills assessment rubric (Liew et al., 2019). The rubric, which was developed after reviewing prior publications, such as Kapici et al. (2019) and Hinkhouse (2013), focused on pre-laboratory activities and when PSPTs were doing activities. It was evident that physicality was a topic of discussion in the literature when comparing the benefits of real versus virtual laboratory experiments. The rubric was developed in order to get insight into the practical activities of PSPTs after they had been taught via blended, virtual, and real laboratory experiments.

The laboratory experiment involving Ohm's law was chosen for laboratory session observation in the study groups for a variety of reasons. Firstly, all the study groups have covered this activity, which was the third in a series of laboratory activities, when the researcher visited the research sites. The researcher intended to observe how the intervention was being implemented during this visit, in addition to observing the laboratory session. Second, compared to other laboratory course activities that were covered during the visit, this laboratory experiment was simple to complete in the allocated period. The essential factor in this case was that all study groups had already covered Ohm's law experiment activity before the observation took place.

3.7. Validity and Reliability of the Instruments

The validity and reliability of the instruments for gathering data were ensured using a variety of approaches. Both before and after the intervention, the Electricity and Magnetism Conceptual Understanding Test (EMCUT), which was taken from the PhysPort developed by the American Association of Physics Teachers, was used. The organization granted permission for the researcher to utilize assessment instruments. These assessment instruments were supported by research and validated. Although these instruments were said to have a good reliability index, they were modified for this research in terms of curricular alignment.

Additionally, by incorporating elements from other assessment instruments, an effort was made to align the instrument with the laboratory course's content. Therefore, language and alignment modifications have to be validated before being used. In order to ensure the new EMCUT test's face and content validity, my supervisor, a PhD candidate in physics education, and two physics teacher educators with more than 10 years of experience teaching at the college level provided comments. These experts provided insightful feedback on a variety of issues, including typographical flaws, clarity, visibility of circuit diagrams, multiple-choice item formats, clarity of the instructions for the question items, and item arrangement. On the basis of expert comments, modifications were made and prepared for pilot testing.

For this study, a 5-scale attitude measure regarding the physics laboratory was adapted and used to gather data from participants. Therefore, 34 items were used to examine participants' attitudes toward the physics laboratory both prior to and following the intervention. The questionnaire's items included a variety of relevant dimensions, such as beliefs, interests, self-confidence, self-efficacy, group learning, enjoyment, and the relevance of physics to everyday life, although these constructs were only examined in aggregate form. These items were modified from earlier works, especially Yesilyurt (2004). The questionnaire items were developed with the objective of gathering data regarding study participants' attitudes toward physics laboratory experiments.

The questionnaires for understanding the nature of science and attitudes toward physics laboratories were translated into Amharic to simplify responses and remove language barriers, though English was the medium of instruction in CTEs. Two English lecturers and a physics education expert reviewed the translation after it had initially been prepared by the researcher after reviewing a number of prior sources. A back translation was then carried out by the researcher and two PhD candidates from the department of science and mathematics. After looking at both the original and the translated versions, changes have finally been made. In order to ensure consistency in the data gathered, the participants were then requested to complete the questionnaire in Amharic. The Amharic and English versions of the questionnaire were provided side by side for clarification.

To check for the reliability of the instruments, the conceptual test items and questionnaires were pilot tested on pre-service physics teachers who were not part of the study. After the pilot test, the Kuder-Richardson coefficient of reliability (KR-20) was calculated for conceptual understanding test items, and Cronbach's alpha was calculated for views on understanding of the nature of science questionnaires and attitudes towards physics laboratory questionnaires. Accordingly, the results obtained for conceptual test items, the VNOS questionnaire, and attitude towards the physics laboratory questionnaire were 0.810, 0.708, and 0.765, respectively, which are all in the range of acceptable values recommended.

3.8. Instructional Materials and Treatments

In this study, two treatment groups (blended and virtual modes of laboratory experimentation) and one comparison group (real laboratory experimentation) were all taught using a guided inquiry-based approach. The laboratory course, which comprised nine experiment activities, served as the instructional material for the comparison and treatment groups. It was ensured that similar experiments would be carried out in the study CTEs based on discussions undertaken with physics teachers and lab technicians prior to the intervention.

With the exception of the type of manipulatives utilized, this laboratory course was given to participants using instructional materials that can help maintain consistency throughout all study groups. The instructional materials included pre-laboratory questions, a description of the specific topic, a list of materials and equipment required in alignment with the three modes of experimentation, experiment procedures, assessment and follow-up procedures, and post-laboratory questions.

The real experimentation involved using physical items, such as wires, bulbs, ammeters, voltmeters, dry cells, switches, and other things typically found in a conventional physics laboratory. Students had access to feedback during real experiments through the system's behavior (for example, when the bulb lights on) and through the instruments used to record the experiment (for instance, ammeters). In the virtual experimentation group, the laboratory experiments were carried out using virtual versions of the real materials, equipment, and instruments on a computer screen. The virtual interactive simulation in the current study did not contain any physical items. The students gained support and guidance in using the mouse to click and drag to engage with the simulation experiments, sliders to change parameters, buttons to select options, and virtual instruments to take readings. In the blended experimentation, students used blended combinations of real and virtual manipulatives per experiment, while taking into account a set of parameters like the objectives of the experiment and the affordances of each type of manipulative. In doing so, an effort was made to evaluate the efficacy of any potential experiment modes that may result from the medium per sec.

The conventional laboratory was integrated with the guided inquiry method to control the confounding variables that might arise due to the difference in instructional strategy, and facilitate pre-service physics teachers' learning when real experiments were conducted. In this approach, the teacher's responsibility is to guide and assist the students in their own learning, and the students are expected to actively seek out solutions to problems. The intervention using virtual experimentation was also facilitated by the guided inquiry method. PhET interactive simulations, which can help teach the activities in the experimental course, were used. The guidelines for PhET-guided inquiry activities were given to the teachers and laboratory technicians in the treatment group (Appendix F). Those that were appropriate were selected for the intervention. In a similar fashion, the blended experiment group was also taught employing a guided inquiry-based approach, demonstrating that the instructional strategy for all the study groups was the same in order to examine for effectiveness in different modes of experimentation. Due to the intervention, some study groups might be at a disadvantage, and ethical concerns might arise because the intervention could likely disturb the students. Pre-service teachers in the comparison group were taught using PhET simulations after the post-test to compensate for what they would have missed.

3.9. Procedure of intervention and data Collection

It is well known that the COVID-19 pandemic has influenced all sectors of a nation across the world. The education sector has also been affected by the pandemic. The same has happened in Ethiopia. Ethiopian schools have been closed for the second semester of the 2019–2020 academic year since the first confirmed COVID-19 patient was found and identified in Ethiopia (Mengistie, 2020). In an effort to cover aspects of the curriculum that had been missed because of school closures, Ethiopian students went through 45-day catch-up sessions at the beginning of the school year (Kim et al., 2021). The academic schedule for the academic year 2020–2021 has been extended as a result of the additional time needed for catch-up. Accordingly, teacher education colleges in Amhara Regional State started the first semester on Monday, January 11, 2021. It was at this point that the implementation of the intervention session started for this study. Off course, visiting research site colleges for preliminary work, offering training to familiarize instructional materials for physics teacher educators and physics laboratory technicians, and introducing PhET virtual interactive simulations took place before the start of class. That is, a first visit, which can be regarded as a baseline visit, has been conducted to the CTEs in order to assess whether the research sites were in comparable conditions with regard to certain criteria for carrying out the research. This includes issues like laboratory settings, the availability of facilities like computers, variables related to teachers and laboratory technicians, and the backgrounds of preservice teachers.

An action plan was prepared to be used as a procedure for data collection. Once the instruments for data collection were prepared and consulted with colleagues and experts, a pilot study was conducted, and then a revision of the instruments was undertaken. The pre-test was administered for treatment and comparison groups through physics teacher educators and physics laboratory technicians. The administration process and the allowed time for each instrument were notified to the implementers. In addition, instructional materials were prepared for participants in blended, virtual, and real experimentation groups. All three study groups were taught with a guided inquiry-based approach. Implementation of the intervention was observed at the beginning, during, and at the end of the treatment period. The researcher made frequent visits and observations at a research site where virtual experimentation was implemented. This was because the researcher wanted to make sure that real materials were not used in the virtual experimentation group before the posttest was administered.

The participants in the real experiment group made use of real materials, equipment, and instruments like wires, resistors, ammeters, voltmeters, switches, and dc power supplies. In contrast, those who participated in the virtual experiment group used virtual instruments and equipment like those displayed on a computer screen. For this group, the interactive simulations from PhET that align with the physics laboratory course were adopted. In the blended experiment group, participants used both virtual and real experiments, based on the learning objective of the experiment.

To control the influence of instructional strategies in the current study, a guided inquiry-based approach was employed in both the treatment and comparison groups. Each of the laboratory materials used by the treatment and comparison groups consists of pre-laboratory activities, objectives of the experiment, an introduction and theoretical background, materials and apparatus required, post-laboratory activities, and follow-up and assessment schemes. The face-to-face training of physics teachers and laboratory technicians lasted for two days in colleges selected as research sites. The training was conducted separately at each site. Pre-service physics teachers were study participants, whereas physics teachers and laboratory technicians at the study sites were implementers. Each implementer received training for its respective experimentation (either blended, virtual, or real) and guided inquiry based approach in common. The physics laboratory technicians at CTEs do a variety of tasks, including gathering laboratory reports, preparing resources, setting up the essential tools and supplies for the laboratory experiment, and assisting students with their investigations. Also, they assist the main physics teacher with the implementation of the physics laboratory course. In other words, they support the proper delivery of the physics laboratory course in every way possible, with the exception of grading marks; however, the teacher may consult on the grade.

3.10. Method of Data Analysis

In the current study, pretest and posttest data analyses of conceptual understanding, understanding of the nature of science, and attitude toward the physics laboratory were carried out to determine the efficacy of a blended mode of physics laboratory experimentation on pre-service physics teachers' learning. The embedded mixed-methods design was used to carry out the current study, as previously described. Based on this design, the researcher simultaneously gathered both quantitative and qualitative data and then used those data to draw a conclusion about the study questions posed.

In the quantitative data analysis, both the pretest and posttest were completed by each student who participated in the study. Each study participant was provided a code that was used to record their quantitative results for conceptual understanding, understanding of the nature of science, and attitude toward the physics laboratory before and after the intervention. In both the pretest and posttest, the 32-item EMCU test score was converted to 100% and recorded. A 5-point Likert scale was used for the understanding of the nature of science and attitude toward physics questionnaires, and the mean values for each dependent variable were recorded for analysis. Descriptive and inferential statistics were used to evaluate the data after ensuring that there were no missing values or outliers. The use of parametric statistics for analysis was supported by a normality test across all the data. Normality tests were performed using graphical and statistical techniques. Moreover, the dependent variables' pretest and posttest scores were subjected to a test of homogeneity of variances. Many of the assumptions were not violated based on the results, with the exception of posttest views of the nature of science questionnaire (VNOS) scores that measure understanding of the nature of science. For VNOS posttest results, the Welch ANOVA was used. Because the assumptions were satisfied, a one-way ANOVA was utilized to analyze the conceptual understanding and attitude toward physics laboratory scores. Also, normalized gains were computed for the conceptual understanding test, and Cohen's d effect sizes and the paired sample t-test were analyzed for all outcome variables.

For the current study, Tukey's Honest Significant Difference post hoc multiple comparison analysis method was used to investigate how groups differed from one another. In the current study, the sample sizes were 16 for the BEG, 26 for the VEG, and 21 for the REG, which were not equal. When there are different group sizes between the experimental and comparison groups, scholars suggest using the Tukey method instead (Lee & Lee, 2018; McHugh, 2015). The Tukey-Kramer variant of the Tukey test and confidence intervals for mean differences are used in the Post Hoc Tests section for samples with different sizes (Lee & Lee, 2018). The Tukey test, as stated by the authors, employs the same sample sizes for groups, but Kramer improved this method to be used with unbalanced data, giving rise to the name Tukey-Kramer test. The Tukey table automatically generates Tukey-Kramer comparisons with unequal sample sizes, so we don't need to do anything special to get Tukey-Kramer results with unequal sample sizes.

A semi-structured interview with a selected set of participants was conducted to capture the intervention's implementation and examine the efficiency of the different physics laboratory experiment modes. The researcher first coded and classified the qualitative data collected from pre-service physics teachers, physics teacher educators, and laboratory technicians through the use of semi-structured interviews. The responses of the pre-service teachers who participated, as well as the physics teachers and laboratory technicians who taught them, were categorized into themes. To determine the interviewee's overall opinions, each interview theme containing numerous captured texts was carefully examined in thematic analysis. When discussing the study's findings, these overall views and comparisons served as a foundation. The data obtained through the laboratory observation checklist were also compared between the treatment and comparison groups. Finally, the results were combined to fully address the research questions and provide a more robust and meaningful picture of the issue under investigation, which is the efficacy of blended laboratory experimentation on the variables examined in this particular study.

3.11. Ethical Issues and Considerations

Educational researchers claim that ethical issues and considerations encompass the whole process of research (Cohen et al., 2007). Thus, attempts were made to adhere to acceptable ethical conduct throughout the study process, from the design of research questions through the selection and design of methodology to the reporting and dissemination of findings. As a result, the researcher used a letter of collaboration from the Department of Science and Mathematics Education at Addis Ababa University to obtain permission from the deans of each college. The objectives and benefits of the study, the roles and responsibilities of the participants, and the challenges and hazards associated with taking part in the study were all thoroughly described at the beginning to ensure awareness and willingness.

To begin the intervention, a letter of permission was submitted to the dean’s offices of the three colleges. They accepted it voluntarily and delegated it to natural science departments, physics teachers who teach the course, and the laboratory technician. The purpose of the research was well explained by the researcher, along with the physics teacher and laboratory technician in each college, when administering the pretest. Participants were recruited entirely on a voluntary basis to take part in this research project. The study's pre-service physics teachers were fully informed about the research protocol and their participation. They were assured that raw data, including participant personal information, was securely stored. To avoid direct identification, participants were coded with numbers. All participants were over the age of 18 and could choose whether or not to participate in the study.

The intervention took place during the actual course schedule. However, the laboratory course was taught in a different way than they were used to. As a result, the pre-service teachers who participated in the study were informed that responding to the data gathering instruments, receiving the intervention, and taking part in the entire study were all voluntary. There was close follow-up in the pretest, during intervention, and posttest. Most importantly, data confidentiality (using codes and pseudonyms when necessary) was given due emphasis. The researcher attempted to reduce bias while marking and processing data and made sure that all the findings reported were based on the data collected. Finally, ways to provide compensation for participant pre-service physics teachers were done in order to maximize their learning since they were disturbed from what they already practiced. As a result, after completing the intervention and taking the posttest, participants in the comparison group received PhET interactive simulation in some experiment activities while leaving other activities to be completed by the teacher and the laboratory technician. Similarly, participants who took part in the virtual laboratory group underwent real laboratory experiments after completing the intervention, leaving additional real experiment activities for the teacher and the laboratory technician to accomplish.

There are also ethical considerations, such as the necessity for honesty, the need for informed consent, the anonymity and maintenance of data, the rights of participants to gain access to data, and the dedication to privacy for all research participants. The participant responses were taken into account when interpreting the interview data, and this was made sure of by disclosing the information to the participants. Also, an attempt was made to use appropriate techniques for data analysis and interpretation guidelines, such as in the interpretation of effect sizes and normalized gains.

This study focused on different types of physics laboratory experiments that necessitate careful health and safety considerations for participants. To ensure these issues were addressed, all participants received training based on the instructional material prepared. Furthermore, the researcher ensured that all participants were available and willing to participate in the study. Participants in the comparison group received training on some selected PhET simulations at the end of the intervention and after administering posttests. By doing this, the primary beneficiaries of the intervention, who are pre-service physics teachers, might be compensated for any wasted opportunities they are anticipated to miss as a result of the intervention.

CHAPTER 4: DATA ANALYSIS and RESULTS

Introduction

The main objective of the current research was to examine how pre-service physics teachers learned of the stated outcome variables by participating in blended, virtual, and real laboratory experiments. In order to achieve this objective, quantitative and qualitative data were collected before, during and after implementing the intervention. That is, pre- and post-tests of conceptual understanding test, understanding of the nature of science questionnaire and attitude towards physics laboratory questionnaire were used to examine the dependent variables both before and after the intervention. In addition, a semi-structured interview was employed after the intervention to get insight into participants' perceptions of the intervention's effectiveness. The chapter presents the analysis of all the data gathered before and after the implementation of real, virtual, and blended modes of physics laboratory experimentation in an effort to find answers to the research questions posed.

Analyses of participant demographic data are presented at the first section of the chapter. Following that, it moves on to the quantitative data analysis by describing any prior differences among the students and determining if the quantitative data adhere to the underlying presumptions of the statistical method being applied. To explore preservice teachers', physics teachers', and lab technicians' perspectives on real, virtual, and blended modes of physics laboratory experimentation, the semi-structured interview was analyzed using theme analysis. The quantitative results were then supported by the qualitative findings, and a detailed discussion with references to earlier studies was performed in the discussion section. The extent to which participants in each mode of experimentation identify materials and equipment and construct circuits after participating in each form of experiment was observed during a laboratory session.

These quantitative and qualitative data were analyzed in order to uncover answers to the study questions posed.

4.1. Demographic Information of Participants

A total of 63 pre-service physics teachers, three physics teacher educators and three physics laboratory technicians participated in the study. The demographic data presented in Table 4.1 below presents the number of pre-service physics teachers in terms of sex in each study group. Male and female ratios were unequally distributed in the settings. Participants in the three groups were all enrolled in the second year of the linear physics diploma, were around the same age, and had completed grade 12. The study involved 63 second-year physics college of teacher education students (N=16 for the blended experiment group, N=26 for the virtual experiment group, and N=21 for the real experiment group) in three different CTEs. Table 4.1 presents the participants demographic data stratified by gender and group.

Table 4.1 *Demographic information of participants*

Study Group	Number	Sex		Total
		Female	Male	
Blended Experiment Group	Count	4	12	16
	%	25.0	75.0	100.0
Virtual Experiment Group	Count	2	24	26
	%	7.7	92.3	100.0
Real Experiment Group	Count	4	17	21
	%	19.0	81.0	100.0
Total	Count	10	53	63
	%	15.9	84.1	100.0

As shown in Table 4.1, the total number of participants in three CTEs were 63, with 53 (84.1%) of the participants being males and the remaining 10 (15.9%) being females. This demonstrates that fewer students are enrolling than are required by the institutions to become physics teachers, and the situation is even worse for females. According to some records, this is too low based on government interests. For instance, ESDP V indicated that the government intended to minimize the gender gap that currently exists among teacher candidates, with the goal of obtaining a 50 percent female teacher candidate intake ratio as shortly as possible (MOE, 2015). On the one hand, the number of pre-service physics teachers is declining, with the proportion of females particularly poor. According to the data in the current study, females are still underrepresented in physics on a global scale, and as a result of this gender disparity, few females hold executive roles in the fields of science and technology.

The results of the current study are consistent with studies that have shown that females are underrepresented in the field of physics on a global scale and that, as a result of this gender disparity, they are still underrepresented in leadership roles in the sciences and in technology fields (Milner-Bolotin, 2015). Furthermore, all pre-service physics teachers who took part in the study had completed preparatory high school, or grade 12. This result gives insight about prior status of the participants of the study. Additionally, because of the vastly disparate sizes of the participants' male and female populations, it was unfeasible to compare sex in terms of experimentation mode. The results of the study are outlined below, organized by the research questions.

4.2. Conceptual understanding in the three modes of laboratory experiments

The main objective of the current study was to examine how well PSPTs learned about electricity and magnetism through blended laboratory experimentation as compared to virtual and real ones.

This leads to the following broad research question, which can be expressed as:

> *Would there be any differences in how PSPTs in the treatment and comparison groups learned the concepts of electricity and magnetism in the physics laboratory?*

Conceptual understanding was one of the outcome variables that were measured. As part of addressing the research problem, the first research question was formulated as stated below in relation to conceptual understanding.

Research question one: Will there be any differences in conceptual understanding among the groups of PSPTs taught with blended, virtual, and real modes of laboratory experimentation in their learning of electricity and magnetism?

A conceptual survey of 32 EMCU multiple-choice test was given both before and after the intervention in order to provide answer to the first research question. The primary objective of the test was to determine whether different modes of laboratory experimentation resulted to a better conceptual understanding of concepts related to electricity and magnetism. For this instrument, the participant received a score of 1 for each correct response and a score of 0 for each incorrect response. In both the pretest and posttest, the participant test responses were assigned a score on an scale of 0 to 32. The maximum score on the pretest and posttest was 32, which, when multiplied by 3.125, yielded a score out of 100. Following that, comparisons were conducted using the score out of 100.

4.2.1. Checking statistical assumptions for the scores of conceptual understanding

To identify the types of data analysis techniques, test scores for the pretest and posttest on conceptual understanding were checked for statistical assumptions. Pretest and posttest were administered at the beginning and end of the intervention, respectively. A participant with a high score of conceptual understanding test was considered to have a high level of conceptual understanding of electricity and magnetism concepts included in the laboratory course. The mean scores of these participants for the dependent variables explained were used to determine whether there was a statistically significant difference among the treatments and comparison groups to examine the effectiveness of the different modes of physics experimentation.

We know that all parametric tests work under certain assumptions about the data which are requirements we must fulfill before conducting data analysis. Testing of these statistical assumptions allows us to draw desired conclusions from the results of data analysis. The pretest and posttest results of the conceptual understanding test are presented in this section, along with a check of test results for statistical assumptions. As a result, it was found by graphical analysis of histograms, Q-Q normal plots, and box plots that the pretest and posttest results of the conceptual understanding test scores for the treatment and comparison groups were distributed approximately normally. Apart from the graphical methods, statistical methods were employed to test normality of data.

Table 4.2 shows descriptive statistics, skewness, kurtosis, and the respective Z-scores of skewness and kurtosis of treatment and comparison groups on pre-test and post-test scores of conceptual understanding.

Table 4.2 *Descriptive statistics of conceptual understanding test scores for the study groups*

Mean scores	Groups	*N*	*M*	*SD*	Skewness			Kurtosis		
					Statistic	*S.E*	*Zs*	Statistic	*S.E*	*Zk*
Pretest scores	Blended	16	30.08	9.26	.56	.56	.99	-.95	1.09	-.87
	Virtual	26	35.94	10.80	.70	.46	1.54	0.65	.887	.73
	Real	21	33.78	7.94	.80	.50	1.60	.56	.972	.58
Posttest scores	Blended	16	40.04	12.46	.74	.56	1.30	-.42	1.09	-.38
	Virtual	26	50.12	12.64	.74	.46	1.61	-.15	.887	-.17
	Real	21	36.91	9.41	-.27	.50	-.54	-.13	.972	-.13

Table 4.2 displays the mean (M), standard deviation (SD), skewness statistics (SS), Z-score for skewness (Zs), kurtosis statistics (KS), and Z-score for kurtosis (Zk). The skewness value of pretest and posttest scores for conceptual understanding test were less than ± 1 and the value of kurtosis was less ± 3. In addition, Z-score values for skewness and kurtosis were computed manually by dividing skewness and kurtosis value by standard error of skewness and kurtosis, respectively, and were found to be less than 3. This held true for every score in the three research groups or levels of independent variable. Though there are inconsistencies in the acceptable value of skewness, kurtosis and Z-score values for skewness and kurtosis, the present values are in the acceptable range (Matore & Khairani, 2020).

As another approach for assessing the normality of data, Table 4.3 presents the numerical tests of Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) to check the normality of scores for the pre-test and post-test of the conceptual understanding test.

Table 4.3 *Statistical test of normality for pre-post conceptual understanding test scores*

Mean test scores	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pretest scores	Blended	.146	16	.200	.912	16	.124
	Virtual	.173	26	.043	.925	26	.058
	Real	.232	21	.004	.915	21	.070
Posttest scores	Blended	.206	16	.069	.916	16	.145
	Virtual	.196	26	.011	.932	26	.086
	Real	.179	21	.079	.912	21	.061

The Shapiro-Wilk test was suggested for small samples in the statistical test of normality displayed in Table 4.3, and the p-value for each level of the independent variable of the pretest scores was larger than 0.05, indicating that the data were derived from an approximately normally distributed population. In addition, the test of normality of the Shapiro-Wilk test for posttest scores of the conceptual understanding test was not found to be statistically significant for all the participant groups ($p > 0.05$). That is, the significance values were 0.145, 0.086, and 0.061 for treatment groups 1, 2, and the comparison group, respectively.

The second assumption that needs to be checked is the homogeneity of variance test, sometimes referred to as Levene's test of equality of variance. In Table 4.4, along with the test of homogeneity of variances, are the conceptual understanding test results from the pretest and posttest for the comparison and treatment groups.

Table 4.4 *Homogeneity of variance for pretest-posttest scores of conceptual understanding*

Mean test scores	Levene's Statistic	df1	df2	Sig.
Pretest scores	.551	2	60	.579
Posttest scores	.798	2	60	.455

As can be seen from Levene's test result in Table 4.4, the equal variances assumption for pretest conceptual understanding was not violated ($p > 0.05$), implying that the equal variances assumption was accepted. Similarly, the test of homogeneity of variances for posttest scores of conceptual understanding was not found to be statistically significant, ($p > 0.05$). That is, the variances of posttest scores of the conceptual understanding test administered for pre-service physics teachers' were equal, $F (2, 60) = 0.798$, $p = 0.455$. That is, the variances of the dependent variable were not different among the comparison and treatment groups. It indicates that the null hypothesis, according to which the variances of the mean pretest and posttest scores for conceptual understanding were the same for each group, was accepted.

One approach to performing an analysis of variance is to assume that if the groups were actually equivalent at the pretest, a one-way ANOVA on the posttest results should be adequate to examine differences between the treatments and comparison groups. Conceptual understanding pretest results were analyzed as indicated in Table 4.5 to check the assumption that the study groups are statistically equivalent at baseline, the time the pretest is administered.

Table 4.5 *ANOVA output for conceptual understanding pretest scores of the study groups*

Source	SS	df	MS	F	*p*
Between Groups	340.12	2	170.06	1.87	.163
Within Groups	5463.06	60	91.05		
Total	5803.17	62			

The first part of the analysis assists in determining the initial comparability of the groups and, consequently, in assessing their impact on the study's outcome variable. The results of the ANOVA analysis are shown in Table 4.5 to determine if there was a difference in the pretest mean conceptual understanding scores between the treatment and comparison groups. The results showed that there was no statistically significant difference in conceptual understanding pretest mean scores between the comparison and treatment groups, $F(2,60) = 1.87$, $p > 0.05$. This suggests that the treatment and comparison groups had comparable levels of initial conceptual understanding of concepts related to electricity and magnetism.

Let's begin discussion by analyzing the mean differences between pretest and posttest scores, which are presented in Table 4.6 below, to see if each group has shown a difference in learning about electricity and magnetism during the intervention period.

Table 4.6 *Conceptual understanding mean difference between pretest and posttest scores*

		Pretest		Posttest		Mean Difference
Group	*N*	*M*	*SD*	*M*	*SD*	
Blended Experiments	16	30.08	9.26	40.04	12.46	9.96
Virtual Experiments	26	35.94	10.80	50.12	12.64	14.18
Real Experiments	21	33.78	7.94	36.91	9.41	3.13

As can be realized from the data in Table 4.6, the treatment and comparison group mean scores in the pretest varied from a minimum of (M = 30.08, SD = 9.26) for the Blended Experiments Group (BEG) to a maximum of (M = 35.94, SD = 10.80) for the Virtual Experiments Group (VEG). That means, there seemed to be a pretest mean difference of 5.86 between the three groups in the pretest. In the posttest, the three groups seemed to score better, with a minimum mean score of (M = 36.91, SD = 9.41) for the real experiment group and a maximum mean of (M = 50.12, SD = 12.64) for the virtual experiment group. That means, the mean difference between groups had become larger in the posttest ($\Delta M = 13.21$).

From this result, it can be determined that the mean and standard deviation scores at the pretest and posttest for BEG were (M = 30.08, SD = 9.26) and (M = 40.04, SD = 12.46), respectively. This yields a difference in mean (MD = 9.96) scores in favor of the posttest. Meanwhile, the mean and standard deviations of VEG for the pretest and posttest of the conceptual understanding test were (M = 35.94, SD = 10.80) and (M = 50.12, SD = 12.64), respectively. This results in a mean gain of (MD = 14.18) scores in favor of the posttest. For the comparison group (real laboratory group, REG), the mean and standard deviations of conceptual understanding pretest and posttest scores are (M = 33.78, SD = 7.94) and (M = 36.91, SD = 9.41), respectively. Similarly, this yields a mean gain of (MD = 3.13) in favor of the posttest.

The mean scores of the measurements taken during the pretest and posttest were compared for each of the three groups using a paired-sample t-test, as shown in Table 4.7.

Table 4.7 *Paired sample t-test and mean differences between pre- and post-tests*

		Pretest		Posttest							
Group	*N*	*M*	*SD*	*M*	*SD*	MD	SD_{md}	*t*	*df*	*p*	Cohen's d
BEG	16	30.08	9.26	40.04	12.46	9.96	14.35	2.78	15	.01	.694
VEG	26	35.94	10.80	50.12	12.64	14.18	10.28	7.04	25	.00	1.38
REG	21	33.78	7.94	36.91	9.41	3.13	11.52	1.24	20	.23	.271

Table 4.7 shows the pretest and posttest means, mean differences, standard deviations, standard deviation of the mean difference (SD_{md}), t-test result, p-values, and effect sizes. The results showed that the blended and virtual laboratory groups had significant gains in conceptual understanding because of the intervention. The comparison group, on the other hand, had no statistically significant improvement. The results in the difference section were computed at $p<.05$ (two-tailed test) and represented changes from the pretest to the posttest. Moreover, effect sizes were calculated on conceptual understanding gains to compare the impact of the blended, virtual, and real experimentation with each group. According to Cohen (1988), d=.80 indicates a large effect size, d=.50 denotes a medium effect size, and d=.20 represents a small effect size. Table 4.7 shows that the virtual experiment group appeared to have the highest effect size with large effect size (d=1.38), followed by the blended experiment group, which had a medium effect size (d=.694). The real experiment group, however, had the lowest effect size with a small effect size (d=.271).

In summary, the differences in mean between pretest and posttest scores for the blended, virtual, and real laboratory groups were 9.96, 14.18, and 3.13, respectively, with the virtual treatment group having the highest mean gain. The difference in means between two points in the study time for the treatment and comparison groups demonstrated improvements in the quasi-experimental intervention implemented. Based on this scenario, it can be inferred that the virtual laboratory experimentation was helpful in improving the mean overall scores of pre-service physics teachers' on the conceptual understanding of electricity and magnetism concepts. Meanwhile, in terms of conceptual understanding test mean scores, the blended physics laboratory experimentation group is lower than the virtual but greater than the real physics laboratory experimentation group.

The results of a one-way ANOVA analysis are displayed in Table 4.8 to illustrate if the difference in the posttest mean scores was significant.

Table 4.8 *ANOVA output for conceptual understanding posttest scores of the study groups*

Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Between Groups	2237.08	2	1118.54	8.29	.001	.217
Within Groups	8092.41	60	134.87			
Total	10329.49	62				

The results of the one-way ANOVA are displayed in Table 4.8 for the difference in the mean conceptual understanding posttest scores for pre-service physics teachers across the treatment and comparison groups. After the intervention, it was demonstrated that there was a significant difference in mean scores between groups, $F(2, 60) = 8.29$, p=.001, η^2 =.217. According to Cohen (1988), this effect size falls under the category of large effect, and it can be said that the modes of experimentation used had an effect on 21.7% of the variation in posttest conceptual understanding scores. According to this scenario, there was significant difference in mean of conceptual understanding posttest scores of pre-service teachers taught the physics laboratory course consisted of concepts of electricity and magnetism through blended, virtual, and real laboratory experimentation.

The Tukey post hoc test was conducted to locate where the significance difference exists as presented in Table 4.9 below.

Table 4.9 *Tukey Post hoc test for conceptual understanding posttest scores*

(I) Group	(J) Group	MD (I-J)	*SE*	*p*
Treatment group1 (BEG)	Treatment group 2 (VEG)	-10.08	3.69	.022
	Comparison group (REG)	3.13	3.85	.696
Treatment group 2 (VEG)	Comparison Group (REG)	13.22	3.41	.001

The Tukey post hoc test of posttest mean conceptual understanding scores for PSPTs in treatment 1, treatment 2, and comparison group is shown in Table 4.9. The results showed that there was a significant difference in mean posttest scores of conceptual understanding test of PSPTs' taught with virtual and blended physics laboratory experimentation (*MD*= -10.08, p =.022). It was also revealed that there was a significant difference in the mean posttest scores of conceptual understanding test of PSPTs' taught with real and virtual physics laboratory experimentation (*MD*= 13.22, p =.001). There was, however, no evidence to support the null hypothesis that there was a significant difference in posttest scores between PSPTs taught through blended and those taught through real laboratory experiments (MD = 3.13, p =.696). The significant mean difference is calculated at the 0.05 level in this case. The mean plots in Figure 4.1 make it easier to see how conceptual understanding changed following the intervention.

Figure 4.1: *Mean plots of conceptual understanding scores*

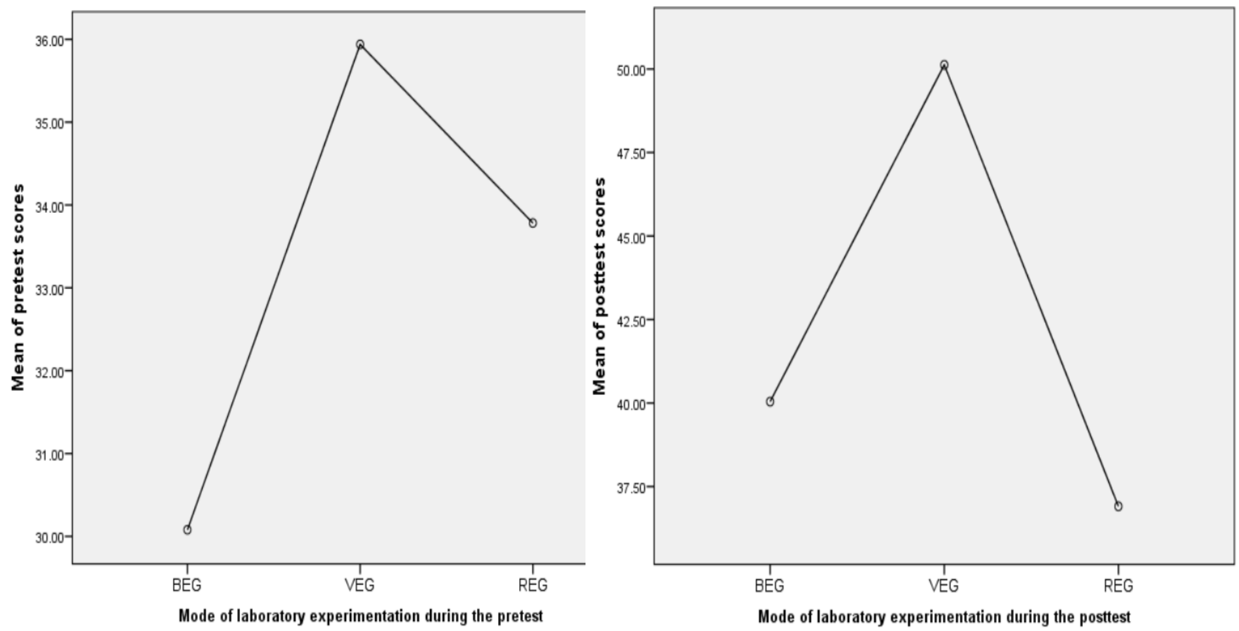


Figure 4.1 shows mean plots of pretest and posttest mean scores of the conceptual understanding test drawn against the mode of physics laboratory experimentation. In the pretest, the virtual experiment group scored better than the others, followed by the real and then the blended laboratory group. Following the intervention, similarly, the virtual experiment group achieved higher scores, followed by the blended experiment group. The real experiment group, however, scored the lowest of all the three groups. Compared to the pretest scores, the VEG was still the highest, followed by the BEG. However, the REG group was the second in the pretest scores, and it scored the least of all the three groups after the intervention.

Furthermore, the normalized gain (gain of averages) was computed from average pretest and average posttest scores for each study groups using Hake's gain (Hake, 1998):

$$\langle g \rangle = (< posttest > - < pretest >)/(100 - < pretest >)$$

This technique is thought to differentiate between teaching interventions for a varied student population with widely differing level of understanding. That is, it is unaffected by student population or pretest scores, allowing researchers and teachers to compare the learning of their students to that of other students who have received other types of instruction (Von Korff et al., 2016). Normalized gain, to put it another way, is the fraction of concepts learned by a group or class that were unknown at the start of the intervention course (Coletta & Steinert, 2020). According to Hake (1998) interpretation guideline, a normalized gain score of $\langle g \rangle \geq .7$ is considered high, $.3 \leq \langle g \rangle < .7$ is categorized as medium, and $\langle g \rangle < .3$ is considered as low. The calculated normalized gain of conceptual understanding test scores of PSPTs' taught using blended, virtual, and real physics laboratory experimentation were .142, .221, and .047, respectively. It can be concluded that preservice physics teachers who were taught through blended, virtual, and real experimentation gained 14.2%, 22.1%, and 4.7%, respectively, of the maximum percentage scores they could have gained from pretest to posttest conceptual understanding test. Despite the fact that there was relative variation among the three groups, the computed normalized gain was low, according to the interpretation guideline (Hake, 1998).

In sum, different techniques were used to analyze the data gathered to investigate the effectiveness of blended mode of laboratory experimentation over solely virtual and real laboratory. The results revealed that virtual mode of laboratory experimentation was better than blended laboratory experimentation which in turn was better than real laboratory experimentation. Applying the paired-sample t-test analysis, there was a significant increase in PSPTs' conceptual understanding when taught using blended and virtual modes of laboratory experimentation. However, there was no significant improvement in conceptual understanding of PSPTs' taught using real laboratory experimentation. However, there was a slight increase in the PSPTs' mean scores of conceptual understanding test from the pretest to the posttest. Even though there were relative differences, the normalized gain computation showed that all three groups placed into the low category. Also, the effect sizes analysis revealed that receiving VE had a large effect on enhancing college students' understanding of electricity and magnetism concepts, but receiving BE and RE had a medium and small effect, respectively.

4.3. Understanding of the NOS in the three modes of laboratory experiments

Understanding of the nature of science was the second outcome variable measured to determine the efficacy of blended physics laboratory experiments. The second research question was designed in relation to understanding of the NOS as part of addressing the research the topic in question, which is outlined below.

Research question two: Will there be any differences between the groups of PSPTs taught using blended, virtual, and real modes of laboratory experimentation in their understanding of the NOS?

The second purpose of the research was to determine whether there was a statistically significant difference between the comparison and treatment groups' posttest scores on students' understanding of the nature of science. Second-year CTE physics students were provided with both quantitative and qualitative data gathering tools in order to investigate this. The quantitative data gathering instrument included 14 questionnaire items with a closed-ended, five-point Likert scale that asked participants to assess how well they agreed with statements about various aspects of the nature of science. The mean deviations between pretest and posttest for each group were computed prior to statistically comparing the groups. This was done to determine whether or not each group had significantly improved throughout the intervention period in their understanding of the nature of science. For the qualitative component, participants were required to write brief explanations of

6 selected aspects of nature of science. The researcher used previous studies to categorize participant replies about conceptions of the nature of science into three levels: informed, mixed, and naive explanations. After repeating the analysis, the results were compared, and inconsistencies were resolved by consulting the data again. To maintain the reliability of the scores, it would have been beneficial if the rating had been completed by different individuals.

4.3.1. Statistical assumptions for scores of understanding of the nature of science

Graphical inspection of histograms, Q-Q normal plots and box plots were examined and it was found that pretest and posttest scores of understanding of the nature of science for the treatment and comparison groups were found to be distributed approximately normally.

Table 4.10 *Descriptive statistics on understanding of the nature of science scores*

Mean scores	Groups	*N*	*M*	*SD*	Skewness			Kurtosis		
					Statistic	*S.E*	*Zs*	Statistic	*S.E*	*Zk*
Pretest scores	Blended	16	3.90	.347	.404	.564	.716	.707	1.09	.649
	Virtual	26	3.80	.386	-.781	.456	-1.71	.635	.887	.716
	Real	21	3.93	.426	-.708	.501	1.41	-.043	.972	.044
Posttest scores	Blended	16	3.99	.474	.055	.564	.098	-.774	1.09	-.710
	Virtual	26	3.96	.274	-.549	.456	-1.20	.630	.887	.710
	Real	21	3.94	.347	-.104	.501	-.208	-.522	.972	-.537

Table 4.10 displays the dependent variables' skewness statistics (SS), Z-score for skewness (Zs), kurtosis statistics (KS), and Z-score for kurtosis (Zk). The skewness value of pretest scores of understanding of the nature of science was less than ± 1 and the value of kurtosis was less than ± 1. In addition, Z-score values for kurtosis and skewness were computed manually by dividing

skewness and kurtosis value by standard error of kurtosis and skewness, respectively, and were found to be less than ± 1.96. Though there are inconsistencies in the acceptable value of skewness, kurtosis and Z-score values for skewness and kurtosis, the present values are in the acceptable value (Matore & Khairani, 2020). Similarly, skewness and kurtosis values of posttest scores of understanding of the nature of science were less than ± 1 and the values of Z-score were less than ± 1.96. The results revealed that the data were approximately normally distributed. Similarly, skewness and kurtosis values of posttest scores of understanding of the nature of science were less than ± 1 and the values of Z-score were less than ± 1.96. The results indicated that the data were approximately obtained from a population with a normal distribution.

Table 4.11 *Statistical test of normality for understanding of the NOS scores*

Mean test scores	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	*p*	Statistic	df	*p*
Pretest scores	Blended	.157	16	.200	.926	16	.214
	Virtual	.137	26	.200	.946	26	.183
	Real	.197	21	.032	.931	21	.142
Posttest scores	Blended	.116	16	.200	.962	16	.703
	Virtual	.169	26	.053	.949	26	.215
	Real	.131	21	.200	.965	21	.618

As displayed in Table 4.11 above, the Shapiro-Wilk and Kolmogorov-Smirnov test was performed to see whether the pretest and posttest scores for understanding of the nature of science adhere to the assumptions of normality. The Shapiro-Wilk test is recommended for small sample sizes (<50 samples), as was previously noted. The finding showed that none of the three groups had any statistically significant departure from normality, $p>.05$ for all the three study groups. That is, the result demonstrated that the distribution of understanding of the nature of science pretest and posttest scores were not departed significantly from normality for each level of the independent variables.

The second assumption that needs to be checked is the homogeneity of variance test. In Table 4.12, the homogeneity of variances of variance test for the pretest and posttest understanding of the nature of science scores are presented for the comparison and treatment groups.

Table 4.12 *Test of homogeneity of variance for understanding of the NOS scores*

Mean test scores	Levene's Statistic	df1	df2	*p*
Pretest scores	.455	2	60	.637
Posttest scores	3.87	2	60	.026

As can be seen from the result in Table 4.12, the pretest and posttest scores for understanding of the nature of science displayed homogeneity of variances, as calculated by the Levene's test for equality of variances, with a *p*- value greater than .05 for pretest scores and a *p* - value less than .05 for posttest scores. We can infer from the data that the equal variances assumption was maintained for pretest scores because these did not differ significantly. That is, there were no differences in the three groups' understanding of the nature of science pretest score variances. The variances within the groups are all of the same nature. On the other hand, as shown in Table 4.12, F (2, 60) = 3.87, p = .026; Levene's test of variances test showed that the variances for posttest scores were statistically significant. This assumption was not met, hence the result for posttest scores was reported using a different method.

One-way ANOVA compares three or more groups under the assumption that the samples were taken from populations with equal variances. However, the Levene's homogeneity of variances test showed that the variances of the posttest scores for understanding of the NOS were found to be significantly different. Hence, Welch and Brown-Forsythe versions of one-way ANOVA that do not rely on the assumption that all groups were sampled from populations with equal variances could be adopted (Frost, 2018). The same rules that apply to the one-way ANOVA table apply to the interpretation of the *p*-value. According to recommendation from the authors, the Welch test is favored in most circumstances, with the exception of when the data are not normally distributed. The understanding of the nature of science posttest scores in the current study were normally distributed, hence the Welch test was calculated and reported.

As shown in Table 4.13, mean, standard deviations, and mean differences were used to compare the pretest and posttest difference in mean scores of understanding of the nature of science for comparison and treatment groups.

Table 4.13 *Pretest-posttest mean difference for understanding of the NOS*

		Pretest		Posttest		
Group	N	M	SD	M	SD	MD
Blended Experiments	16	3.90	.347	3.99	.474	.09
Virtual Experiments	26	3.80	.386	3.96	.274	.16
Real Experiments	21	3.93	.426	3.94	.347	.01

As it is indicated in Table 4.13, the mean difference seems very slight. The result revealed that the groups mean scores in the pretest varied between the minimum (M=3.80, SD=.386) for Virtual Experiment Group to a maximum of (M= 3.93, SD=.426) for the Real Experiment Group. That means, there seemed to be a pretest mean difference of .13 between the three groups in the pretest. In the posttest, the three groups seemed to score slightly better with a minimum mean score of (M=3.94, SD=.347) for Real Experiment Group to the maximum mean of (M=3.99, SD=.474) for the Blended Experiment Group. That means, the mean difference between groups had become smaller in the posttest (ΔM=.05). The Virtual Experiment Group outperformed the other group with mean difference (MD=.16), followed by the Blended Experiment Group (MD=.09), when the pretest-posttest mean differences were computed for each group.

The paired-sample t-test was used to see if the differences in mean scores were statistically significant. Nearly all of the computed effect sizes for each group fell into the small effect category. It may be inferred that neither the treatment group participants nor the comparison group participants improved their understanding of the most of the aspects of the nature of science.

Table 4.14 *Paired-sample t-test for understanding of the NOS scores*

Pair	*M*	*SD*	*t*	*df*	*p*	Cohen's d
BEG Posttest-Pretest	.09	.30	-1.17	15	.261	.30
VEG Posttest-Pretest	.16	.44	-1.79	25	.086	.36
REG Posttest-Pretest	.01	.46	-.15	20	.880	.02

Table 4.14 shows the results of a paired-sample t-test to determine whether there was a significant difference in the mean views of the nature of science (VNOS) scores at pretest and posttest after

exposing PSPTs to real, virtual and blended modes of laboratory experimentation. Accordingly, neither the treatment groups nor the comparison group showed significant difference because of the interventions employed. Pre-service physics teachers who were taught using all three types of laboratory experimentations showed no significant change in their understanding of nature of science when compared before and after the intervention.

The other presumption that needs to be verified is whether or not the pretest results, which were obtained before to the intervention, are comparable. This will help determine the statistical method that will be used to compare the posttest results. Table 4.15 shows the results of the one-way ANOVA analysis for the pretest scores on understanding of the NOS for the treatment and comparison groups.

Table 4.15 *ANOVA output for understanding of the NOS pre-test scores*

Source	SS	df	MS	F	*p*
Between Groups	.210	2	.105	.688	.506
Within Groups	9.15	60	.153		
Total	9.36	62			

As indicated in Table 4.15, there was no significant difference in mean conceptual understanding pretest scores between the treatment and comparison groups, $F(2,60) =.688$, $p =.506$. It can be deduced that the baseline levels of the participants in the treatment and comparison groups were equivalent prior to the intervention.

To ascertain whether there were statistically significant differences between the means of the three study groups based on understanding of the nature of science, the one-way analysis of variance (ANOVA) was computed for posttest scores. The Welch robust test of equality of means was performed and reported since the posttest scores did not meet the homogeneity of variances assumptions.

Table 4.16 *Robust tests of equality for posttest scores of understanding of the NOS*

Test	Statistic	df1	df2	*p*
Welch	.050	2	31.990	.951

As indicated in Table 4.16, robust tests of equality of means revealed a non-statistically significant result, Welch's F (2, 31.99) = 0.050, p >.05. This means that there was no statistically significant difference in the mean posttest scores of understanding of the NOS between PSPTs taught through real, virtual, and blended modes of physics laboratory experimentation. In other words, the Welch's test outputs revealed no significant differences in posttest scores across the three groups. It can be implied that none of the three modes of physics laboratory experimentation significantly enhance understanding of the NOS components. That is, understanding of the NOS aspects was unaltered by changing the modes of physics laboratory experimentation.

Following the intervention, pre-service physics teachers were asked to write on six selected NOS aspects, including scientific theories and laws, tentativeness, social and cultural embeddedness, observations and inferences, and creativity and imagination. Their explanations were classified as naïve, mixed, or informed. Table 4.17 summarizes the results.

Table 4.17 *Kruskal-Wallis test results about the six NOS elements*

Aspects of nature of science	Group	N	Mean Rank	df	χ^2	Asymp.Sig
	BEG	16	34.78			
Observations and Inferences	VEG	26	29.79	2	1.05	.592
	REG	20	31.10			
	BEG	16	30.66			
Tentativeness of scientific knowledge	VEG	26	37.06	2	6.26	.044
	REG	20	24.95			
	BEG	16	24.28			
Scientific theories and laws	VEG	26	31.90	2	5.55	.062
	REG	20	36.75			
	BEG	16	25.88			
Social and cultural embeddedness	VEG	26	35.02	2	3.08	.215
	REG	20	31.43			
	BEG	16	20.44			
Creativity and imagination	VEG	26	36.35	2	9.69	.008
	REG	20	34.05			
	BEG	16	26.75			
Scientific methods	VEG	26	36.62	2	4.24	.120
	REG	20	28.65			

As shown in Table 4.17, there was no significant statistical difference in the mean ranks of many of the aspects of NOS, $\chi^2(2) = 1.05$, $p = .592$, $\chi^2(2) = 5.55$, $p = .062$, $\chi^2(2) = 3.08$, $p = .215$, and $\chi^2(2) = 4.24$, $p = .120$ for observations and inferences, scientific theories and laws, socio-cultural embeddedness, and scientific methods, respectively. However, there was a significant difference in mean posttest scores of PSPTs' taught using different modes of laboratory experimentation for creativity and imaginative and tentativeness of scientific knowledge $\chi^2(2) = 6.96$, $p = .008$ and $\chi^2(2) = 6.26$, $p = .044$, respectively. From the results, it can be deduced that participants who were taught using virtual laboratory experiments had a superior understanding of the tentativeness of scientific knowledge and the creativity and imaginative aspects of science than those who were taught using blended and real experiments.

4.4. Students' attitude towards physics laboratory in the treatment and comparison groups

The third outcome variable measured to determine the effectiveness of blended physics laboratory experimentation was attitude toward physics laboratory. In order to address the research problem under investigation, the third research question was designed in relation to attitude toward physics laboratory, which is stated below.

Research question three: Will there be any differences in attitude towards physics laboratory among the groups of PSPTs taught with blended, virtual, and real modes of laboratory experimentation in their learning of electricity and magnetism?

Pre-and post-attitude measurements were made using a scale for measuring attitude towards physics laboratory. The 34 items in the questionnaire about attitudes regarding physics laboratories ranged in weight from 1 to 5, with 5 representing strongly agree and 1 representing strongly disagree. Higher scores were associated with more favorable responses because the 5-point Likert Scale was used to categorize student responses to the test. The overall attitude toward the physics laboratory score reflects how much the student agrees or disagrees with the physics laboratory experiments. The score for the negative items is recoded so that all the items have a positive value of measurement. Scores below 3.0 suggest an unfavorable attitude toward physics laboratory, and scores above 3.0 indicate a favorable attitude toward physics laboratory, despite the fact that there are several interpretation criteria in the literature.

4.4.1. Statistical assumptions for the scores of attitude towards physics laboratory

The pretest and posttest scores of attitude toward physics laboratory questionnaire demonstrated that the data were approximately normally distributed using graphical methods such as histograms, Q-Q normal plots, and boxplots. Before conducting analysis and interpretation, descriptive and statistical checks of assumptions of these scores of attitude toward physics laboratory were undertaken. Table 4.18 conveys descriptive statistics, skewness, kurtosis, and the respective z-scores for pretest and posttest scores of attitude towards physics laboratory for the treatment and comparison groups.

Table 4.18 *Descriptive statistics on attitude towards physics laboratory for the study groups*

Mean scores	Groups	*N*	*M*	*SD*	Skewness			Kurtosis		
					Statistic	*S.E*	*Zs*	Statistic	*S.E*	Z_k
Pretest scores	Blended	16	4.20	.315	-.627	.564	1.11	1.16	1.09	1.06
	Virtual	26	4.05	.256	.075	.456	.164	.214	.887	.241
	Real	21	4.12	.309	-.919	.501	-1.83	1.14	.972	1.17
Posttest scores	Blended	16	4.46	.275	-.893	.564	-1.58	.739	1.09	.678
	Virtual	26	4.24	.315	.006	.456	.013	-.610	.887	-.688
	Real	21	4.13	.356	-.479	.501	-.956	-.113	.972	-.116

As indicated in Table 4.18, the skewness for pretest and posttest scores of attitude towards physics laboratory was less than ± 1 which implies that the scores were approximately normally distributed. Besides, the kurtosis of pretest and posttest scores of attitude towards physics laboratory were close to ± 1 which implies that the scores were approximately normally distributed. Moreover, the Z-scores for pretest and posttest scores of attitude towards physics laboratory for all the independent levels were less than ± 1.96.

The kurtosis, skewness, and respective z-scores of posttest attitude toward physics laboratory were shown to have values near to the acceptable normality ranges. Thus, the results indicated that the data were approximately normally distributed. In addition, statistical test of normality was also employed to check for normality of pretest and posttest scores of attitude towards physics laboratory. The results are presented in Table 4.19.

Table 4.19 *Statistical test of normality for attitude towards physics laboratory scores*

Mean scores	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pretest scores	Blended	.143	16	.200	.957	16	.608
	Virtual	.169	26	.054	.959	26	.380
	Real	.140	21	.200	.930	21	.139
Posttest scores	Blended	.188	16	.134	.893	16	.061
	Virtual	.135	26	.200	.964	26	.484
	Real	.130	21	.200	.958	21	.478

In the statistical test of normality given in Table 4.19, the p-value for each level of the independent variable was larger than.05, indicating that the data were approximately in a normal distribution.

The Shapiro-Wilk test was advised for small samples. As shown in Table 4.19, the findings showed that there was no statistically significant difference between BEG, VEG, and REG when measured by the Shapiro-Wilk test (W), W (16) =.893, p=.061, W (26) =.964, p=.484, and W (21) =.958, p=.478, for BEG, VEG, and REG, respectively. The scores were not deviated from normal distribution. That is, at each level of the independent groups, the Shapiro-Wilk statistical test of normality for posttest scores of PSPTs' attitude toward physics laboratory was not statistically significant. It can be concluded that the treatment group's levels (independent variable) were approximately normally distributed, and the normality conditions were met.

The other assumption that needed to be checked in relation to the attitude toward the physics laboratory outcomes from the pretest and posttest was the homogeneity of variance test. For the treatment and comparison groups, the results of the pretest and posttest on attitude toward physics laboratory are displayed in Table 4.20.

Table 4.20 *Homogeneity of variance for the scores of attitude towards physics laboratory*

Mean Scores	Levene's Statistic	df1	df2	Sig.
Pretest scores	.292	2	60	.747
Posttest scores	.827	2	60	.442

As it is displayed in Table 4.20, the Levene's test for equality of variances revealed a significance values, F (2, 60) =.292, p=.747, for pretest scores and F (2, 60) =.827, p =.442, for posttest scores. This implies that the equal variances assumption was upheld for the pretest and posttest scores of attitude toward the physics laboratory (p>0.05), supporting the equal variances assumption. In other words, the Levene's test for equality of variances for the dependent variable revealed that there was homogeneity of variances.

Before statistically comparing the groups, the mean differences between pretest and posttests for each group were calculated. That was to see if each group had showed significant attitudinal change during the intervention period. The pretest and posttest mean scores and the mean differences are presented in the Table 4.21 below.

Table 4.21 *Attitude towards physics laboratory mean differences for the study groups*

		Pretest		Posttest		
Group	*N*	*M*	*SD*	*M*	*SD*	MD
Blended Experiments	21	4.20	.315	4.46	.275	.269
Virtual Experiments	26	4.06	.256	4.24	.315	.179
Real Experiments	16	4.12	.309	4.13	.356	.010

As indicated in Table 4.21, the difference in mean between posttest and pretest attitude towards physics laboratory questionnaire scores for Virtual, Blended and Real groups were 0.269, 0.179, and 0.010, respectively. The groups mean scores in the pretest varied between the minimum of (M=4.06, SD=.256) for the Virtual Experiment Group to a maximum of (M= 4.20, SD= .315) for the Blended Experiment Group. That means, there seemed to be a pretest mean difference of .14 between the three groups in the pretest. In the posttest, the three groups seemed to score better with a maximum mean score of (M=4.46, SD=.275) for Blended Experiment Group to the minimum mean of (M=4.13, SD=.356) for Real Experiment Group. That means, the mean difference between groups had become larger in the posttest (ΔM=.330).

To assess if the differences in mean were statistically significant, the paired-sample t-test was utilized. The difference in mean between posttest and pretest attitude toward physics laboratory questionnaire scores for BEG, VEG, and REG, as shown in Table 4.22, were 0.269, 0.179, and

0.010, respectively. The paired-sample t-test was used to see if the differences in mean from pretest to posttest were statistically significant.

Table 4.22 *Paired-sample t-test for scores of attitude towards physics laboratory*

Pair	*MD*	*SD*	*T*	*df*	*p*	Cohen's d
BEG Posttest-Pretest	.269	.252	4.27	15	.001	1.07
VEG Posttest-Pretest	.179	.236	3.87	25	.001	.758
REG Posttest-Pretest	.010	.304	.158	20	.876	.033

In Table 4.22, the paired-sample t-test is used to assess whether there was a significant difference in the mean scores on the attitude toward physics laboratory questionnaire before and after the PSPTs were exposed to blended, virtual, and real laboratory experimentation. As a result, the treatment groups significantly improved, but the comparison group showed no significant improvement, t (15) = 4.27, $p = .001$, t (25) = 3.87, $p = .001$, and t (20) = 0.158, $p = 0.876$ for blended, virtual, and real experimental groups, respectively.

It can be claimed that when comparing pre-service teachers' attitudes toward the physics laboratory before and after the intervention, those who were taught with blended and virtual experimentation showed a significant improvement, but those who were taught using real physics experiments revealed no significant change. However, there was a slight mean difference favoring the posttest, and they showed a positive attitude in both the pretest and posttest. This non-significant result of attitude toward physics laboratories on PSPTs who were taught using real laboratory experiments could possibly be due to challenges with the equipment, inadequate interaction, routineness of tasks, or their loss of interest. Also, the calculated Cohen's d effect sizes for the blended, virtual, and real experiment groups were 1.07, .758, and .033, respectively. The effect sizes were large for blended, medium for virtual, and small for real experiment groups, according to Cohen's (1988) interpretation guideline.

In order to examine the efficacy of the treatments, comparisons of mean differences should be based on checking the underlying assumptions of the data. Table 4.23 reveals one-way ANOVA analysis result for pretest scores of attitude towards physics laboratory for the study groups.

Table 4.23 *ANOVA output for pretest scores of attitude towards physics laboratory*

Source	*SS*	*df*	*MS*	*F*	*p*
Between Groups	.170	2	.085	1.02	.368
Within Groups	5.03	60	.084		
Total	5.20	62			

As it is conveyed in Table 4.23, there was no significant mean difference on pretest scores of attitude towards physics laboratory between treatment and comparison groups, $F(2, 60) = 1.02$, $p > .05$. The result revealed that pre-service physics teachers who were taken from three CTES and participated in the present study were in a comparable status in relation to their attitude towards physics laboratory experimentation prior to the intervention. As the participants were at comparable baseline levels before to the intervention and the conditions of normality and homogeneity of variances were satisfied, it is possible to perform and report one-way ANOVA as shown in Table 4.24.

Table 4.24 *ANOVA analysis of posttest scores for attitude towards physics laboratory*

DV	Source	*SS*	*df*	*MS*	*F*	*Sig.*
Attitude towards physics	Between Groups	1.04	2	.520	5.08	.009
laboratory posttest scores	Within Groups	6.15	60	.103		
	Total	7.19	62			

As shown in Table 4.24, the one-way ANOVA was used to investigate the efficacy of the three modes of physics laboratory experimentation on attitude towards physics laboratory experiments. It was observed that there was a significant mean difference in posttest scores of attitude towards physics laboratory between at least two groups, F (2, 60) = 5.08, p = 0.009. It can be seen from the results of the ANOVA analysis that there are statistically significant differences between the groups as a whole. Table 4.25 displays the group differences after post hoc multiple comparisons were performed.

Table 4.25 *Tukey Post hoc test for attitude towards physics laboratory posttest scores*

(I) Group	(J) Group	MD (I-J)	SE	ρ
Treatment group1 (BEG)	Treatment group 2 (VEG)	.221	.102	.084
	Comparison group (REG)	.336*	.106	.007
Treatment group 2 (VEG)	Comparison Group (REG)	.115	.094	.441

*Note: *. The mean difference is significant at the .005 level.*

As indicated in Table 4.25, attitude toward physics laboratory scores for the treatment and comparison groups were compared using Tukey post hoc comparisons test. The findings showed that the mean posttest scores of PSPTs in the blended experiment group (M = 4.46, SD =.275) differed significantly (p = .007) from those the real experiment group (M = 4.13, SD =.356). In other words, the mean difference between the blended and real modes of physics laboratory experimentation was significantly different (MD = .336, p = .007). Any differences between the other modes of laboratory experimentation were not significant. There was no significant difference in the mean posttest scores between blended and virtual experimentation (p = .084) or between virtual and real experimentation (p = .441). The results suggest that the blended mode of physics laboratory experimentation significantly improved attitude towards physics laboratory for preservice physics teachers compared to real mode of experimentation. But, the participants responded favorably to blended, virtual, and real modes of physics laboratory experimentation.

4.5. Qualitative data results

Qualitative data includes semi-structured interviews and laboratory session observations. That is, the qualitative part of the research question explores how the different modes of physics laboratory experimentation affect student learning. Besides, it identifies the opinions of participants and their comments for further improvement of the mode of experimentation employed. Observation of a laboratory session took place when students gathered and recorded data about an experiment in the laboratory. In the laboratory, preservice physics teachers are expected to demonstrate a variety of process skills, from asking questions to communicating results. The laboratory session observation in this study, however, focused primarily on identifying real laboratory materials and constructing circuits. The results from interviews with preservice physics teachers, physics teachers and laboratory technicians, and laboratory session observation are reported in the next section.

4.5.1. Results of the interviews with pre-service physics teachers

The interview questions focused on pre-service physics teachers' preferences for the previous and new modes of physics laboratory, the advantages and drawbacks of the newly implemented laboratory manipulatives, their involvement in the experiment activities, interaction among students, with the teacher and laboratory technician, benefits in understanding the physics concepts, and suggestions for further improvement. In general, the qualitative data was collected to provide evidence on pre-service physics teachers' opinions of real, virtual, and blended laboratory experimentation modes, as well as suggestions for future improvement.

In the very beginning of the interview, PSPTs in the blended laboratory group were asked if they noticed any differences between their previous and current physics laboratory courses (Q1). According to the findings of the interview, all participants noticed differences. Except for one participant, who mentioned that the new laboratory learning environment provided us with multiple tasks, their reasons were related to the opportunities that the two (virtual and real) modes of laboratory experiments provide. This participant stated that:

> *The first laboratory course we took was very simple, with few tasks. However, we were now expected to complete lot of tasks, and becoming acquainted with the system was difficult (SB6).*

When asked which type of laboratory experimentation they preferred (Q2), all interview participants agreed that the blended mode was superior to the previous, conventional physics laboratory.

> *I preferred the current laboratory approach because it allowed me to learn both with real apparatus and materials and with simulations through the use of a computer. I can understand concepts that are invisible and difficult to grasp (SB5).*

Other participants expressed a preference for the new approach because of the opportunity it provided for abstract and tangible evidences to understand the associated physics concept, as well as the additional opportunity for discussion and interaction. But many of them emphasized that they were busy and challenged during the session.

> *I prefer the current method of physics laboratory experimentation because it allows me to observe both the abstract and concrete nature of the concept and allows for more opportunities for discussion with friends. Additional time should be allocated and the tasks should be reduced (SB2).*
>
> *I prefer the current laboratory learning method because it provides additional advantages. However, it keeps us busy and exposes us to confusion (SB6).*

Regardless of the challenges they faced or the disadvantages mentioned in other interview questions, all of the interview participants shared this opinion.

When participants asked about the advantages and disadvantages of the blended mode of laboratory experimentation (Q3), all of the interviewee indicated that the new approach has both advantages and disadvantages, though their reasons differed. The benefit of working with real materials while also observing abstract phenomena through interactive simulations was repeatedly mentioned (by 5 out of 6 participants). In summary, the disadvantages mentioned by interview participants include a lack of computer skills, lack of time, shortage of computers to practice on, being overburdened with many tasks, and the difficulty of resolving confusions caused by the two modes of experimentation. One interviewee (SB1) stated that the simulation activity on charging methods was confusing because it did not show grounding.

When asked about their involvement in the new laboratory mode (Q4), all of the participants stated that it allowed them to be more active and interact with one another, the laboratory technician, and the teacher.

In the previous laboratory course, we had rushed to record data and complete the laboratory activity. Only task division was used to read the devices and record data on paper. However, we were more active and engaged with one another, the laboratory technician, and the teacher in this new approach (SB3).

The involvement and interaction we had in the new laboratory method was interesting. However, one interviewee conveyed it differently (SB5).

Yes, the current laboratory experimentation mode enabled us to actively engage and interact with one another, as well as with the teacher and laboratory technician. There was, however, no clear summary or conclusion of the physics concepts learned (SB1).

This interviewee's response is consistent with that of other participants who expressed a shortage of time and the abundance of tasks included in the laboratory experiment activity.

The result of the interview regarding their perceptions of learning (Q5) revealed that all the interview participants stated that the blended mode of laboratory helped them in their understanding of physics concepts better. For example,

The current laboratory approach greatly helped me in understanding charge redistributions in charging methods that are invisible to us and at the same time providing practical experience (SB4).

The current approach of laboratory experimentation was extremely beneficial to me. For example, in the measuring voltage and current experiment, I was able to set up the experiment practically while also observing the phenomenon of electric flow when the polarity of the devices was changed (SB1).

All other participants acknowledged that the blended mode of physics experimentation helped their understanding of physics concepts related to the experiments.

The final question posed to the interview participants was to ask them give suggestions, if any, for further improving the implementation of blended mode physics laboratory experimentation (Q6). The interview results revealed that providing enough access to computers and PhET software training, allocating enough time, preparing an adequate computer room for training, and organizing the laboratory room were the most frequently raised issues by interview participants.

> *It would have been preferable if the experimental activities were carried out first with real materials, followed by the PhET simulations for each activity (SB5).*

The response of this the participant could be related to the idea of sequencing VE and RE when combining the two modes of experimentation.

> *Some of the materials I observed in real materials and in the PhET simulation appear to be different, such as the ends of resistors and switches (SB3).*

The questions raised for the blended laboratory group above were also presented to the virtual laboratory group interview participants. In a similar fashion, the first question posed to the interview participants was whether they noticed any differences between their previous and current laboratory courses (Q1). All the participants of the virtual experiemnt group noticed differences and many of the them stated that the current mode of laboratory experimentation enabled them to observe the phenomena of abstract concepts. They described their comparison in terms of a specific physics concept related to the laboratory activity. That is, the examples they used to explain how they noticed the differences varied.

In the current (virtual) laboratory experimentation, I was able to observe abstract phenomena such as charge redistribution after the charging methods and current flow in a wire (SV6 and SV3).

In the current laboratory learning environment, for example, we can easily change values when measuring current and voltage (SV5 and SV4).

The current laboratory learning environment caught my attention more than the previous one because of the flow of charges and current (SV2).

The deflection of the galvanometer and the movement of the bar magnet impressed me greatly (SV6 and SV2).

I think the new one also has its own advantage (SV1).

Other explanations were presented by interview participants for how they noticed the difference between virtual and real laboratory experimentation.

We were able to work with materials and apparatuses in the previous one. But such things no longer exist. This will cause difficulties in teaching our students in schools (SV1).

Another distinction I noticed is that we have no experience with real objects. I believe that working practical activities will be difficult (SV4).

When asked which type of laboratory experimentation they preferred (Q2), many of (4 out of 6) interview participants agreed that the virtual mode was better than the previous, conventional laboratory, mode. For example,

I prefer the new one (virtual laboratory) because it attracts my attention and allows me to observe abstract phenomena such as flow of current and magnetic field lines (SV5).

I prefer the current one (virtual laboratory) because I had a good discussion with and support from my friend, the laboratory technician, and the teacher (SV2).

The other two participants appeared to be undecided about whether they preferred real or virtual laboratory experimentation. They explained the benefits and drawbacks of the two modes of experimentation during the interview.

It (the virtual laboratory) may help my understanding of the science (the physics concepts). However, when I graduate, I must be good in practical skills. It is difficult to select the one (SV4).

It may be possible to choose between from the two methods. However, each has advantages and disadvantages. If I have to choose, I will prefer the former (the real laboratory experiment) because it will help me teach students in schools (SV3).

The third question posed during the interview was concerned with the advantages and disadvantages of virtual physics laboratory experimentation (Q3). The virtual laboratory experimentation, according to all of the interviewees, helped them in observing and learning abstract phenomena and concepts. Similarly, they all stated that the disadvantages of virtual laboratories are the challenge in using computers, the scarcity of computers, and the lack of interaction with materials. The perspectives of the interviewees on the benefits and drawbacks of virtual laboratory experimentation are as follows.

When we learned in the current laboratory method, there was no waste of material, it was good for abstract and difficult concepts, there was active participation, and we can do it again if necessary. However, we face difficulties in using computers, shortage of computers, electricity problem, no interaction with materials and apparatuses, and inability to observe materials (SV6).

This laboratory approach is useful for abstract concepts as well as motivating us. However, it does not help with practical activities. Many of the materials seen in the simulation are unknown to us, for example resistors and switches. Another problem was using the computer and software (SV4).

The benefits are that it gives values quickly, is safe, saves material costs, and helps in the observation of abstract concepts. However, the current laboratory has drawbacks such as poor computer skill, absence of interaction with materials, computer shortage, and practical skill limitations (SV2).

It will be a good alternative to learn physics laboratory activities if we get good training and computers (SV1).

When asked about their involvement and participation (Q4) in the virtual laboratory experimentation, many of the interviewees (5 out of 6) stated that they were actively participating and involved during the laboratory session.

My friends and I were actively participating in the laboratory activities. Both the laboratory technician and the teacher were extremely helpful (SV6).

We were engaged in active discussion with one another. Things (the PhET simulations) were unfamiliar to us. The laboratory technician and the teacher assisted and encouraged us (SV1).

One of the students explained that, while the participation and interaction were encouraging, using the computer and software was challenging.

I was observing and participating, but using the computer was difficult for me. My interactions with my friends, the technician, and the teacher were all favorable (SV3).

Another interview question that was posed to the participants was how the virtual laboratory experimentation helped them understand physics concepts (Q5). They all have positive perceptions of the role of virtual laboratory experimentation in conceptual learning and explained their answer related to charge distribution and current flow. Two interviewees added magnetic field lines and electromagnetic induction (SV6 and SV2). One interviewee elaborated on factors affecting conductor resistance in particular (SV4). Another interviewee explained it in relation to electromotive force and internal resistance (SV3).

At the end, the interviewees were then requested to make any recommendations for improving the implementation of virtual laboratory experimentation (Q6). The most repeatedly stated suggestion for future implementation improvement was computer training, computer availability, and extra time for practice. Two participants added that real materials and practice should be provided in addition to the virtual laboratory experiments (SV4 and SV3). For instance,

> *I know that the current laboratory approaches have enabled our learning in a variety of ways. But it will be better if we get more computer training, as well as enough computer and real-world materials. In my opinion, I want to learn through practice (SV3).*

According to the results of the interviews, the majority of the students favored virtual laboratory environments to assist them in observing abstract concepts and facilitating interaction with their friends, laboratory technician, and teacher. Other students stated that they need practical experience in order to teach in schools later on. They needed to gain hands-on experience with real-world materials. Some of them stated that they were unfamiliar with some of the materials they saw in PhET simulation, such as resistors and switches. The ability of virtual laboratory experiments to illustrate abstract concepts was the most frequently mentioned advantage. The most frequently mentioned disadvantage was a lack of computer knowledge and a scarcity of computers. It appears that the pre-service physics teachers were unfamiliar with virtual laboratory experiments. Preservice physics teachers might be better able to understand the tools in the PhET simulations, observe the phenomena, and gather data as necessary if they gained additional experience with virtual laboratory experiments.

To explore more about how students feel about implementing real experiments in their learning, semi-structured interviews with real experiment participants have also been conducted. Equivalent semi-structured interview questions were offered, but these were more concerned with carrying out real laboratory experiments. In those interviews, students were primarily questioned regarding the implementation process as well as the impact of using real laboratory experiments on their understanding of the concepts of physics.

All of the participants in the interview noticed the differences between the implemented laboratory course and the previous one for the first interview question (Q1) due to the addition of pre-laboratory, post-laboratory, teacher, and technician support. Two of the participants, however, noted that these questions added to their workload. They were also questioned about their preference for the present strategy over the previous one (Q2). All of the participants said they were at ease with how the laboratory course is currently being delivered. In response to the third interview question (Q3), the participants replied the current approach to presenting the laboratory course provides benefits, such as allowing students to prepare in advance of the laboratory experiment, work on the experiment activity while being guided by the post-laboratory questions, and encourage positive connections with each other, the teacher, and the laboratory technician. For instance, one respondent explained the following in relation to this issue:

Compared to the previous laboratory course, the current approach has given me a better opportunity to prepare in advance, and in the process, to discuss with the teacher, the laboratory technician, and colleagues (SR4).

When asked if they were working actively on their tasks during the laboratory session, each participant said they were (Q4). On the fifth question (Q5), four of the participants stated that the pre- and post-laboratory questions had aided them in understanding the differences between the charging methods (2 participants), the factors affecting a wire's resistance (1 participant), the how and why of ammeter and voltmeter connections in circuits (1 participant), and Faraday's law of electromagnetic induction (1participant). Two of the participants stated that the questions promoted more interaction between their peers, the teacher, and the laboratory technician. In conclusion, the participants who were questioned replied positively to the laboratory course's implementation compared to their previous laboratory course.

4.5.2. Results of interviews with physics teachers and laboratory technicians

Physics teacher educators and laboratory technicians were also interviewed on whether they felt any difference between the previous laboratory approach and the newly implemented one, what advantages and disadvantages they observed and comments and suggestions for further improvement of the interventions.

In the blended laboratory experiment group, the teacher educator and laboratory technician were asked about their perceptions of the newly implemented laboratory mode, its benefits and drawbacks, as well as comments and suggestions for future improvements. The physics teacher educator in the blended mode also noticed the importance and benefits of the newly implemented laboratory mode. Based on the interviewee, the blended approach has helped PSPTs in learning physics better by providing the benefits of both real and virtual laboratories. In virtual laboratories, students were able to observe abstract phenomena such as distribution of charges, flow of current, factors affecting resistance of a conductor, magnetic field lines and electromagnetic induction phenomena and others. They were motivated highly with these benefits and actively participating and interacting. There was also hot discussions in pre-laboratory. The advantages were providing many opportunities for learning different physics concepts, motivation for active participation and engagement for laboratory activities, eager to come to the laboratory room, and open-minded.

The disadvantage was lack of computer skill, shortage of computers, shortage of time, challenge to be acquainted with many tasks, the short time schedule because of COVID-19 pandemic, burden on the physics teacher and laboratory technician, some students did not consider the simulation as seriously as the real laboratory. In the future, students should be given enough training of computer particularly for science and mathematics majors. There must be separate computer and rooms for science and mathematics training. Teaching and learning using interactive simulations should be part of the regular schedule so that it will get emphasis from many parties and answer administrative issues. The laboratory technician and the teacher educator need to get refreshment training on how to help students in computer assisted learning though there were limited training given by universities. These are not based on need assessment.

The laboratory technician replied that the approach was important for students learning since it used interactive simulations that helped them learn abstract and difficult concepts easily. It initiated them for active participation and engagement. They were far more attracted and concerned than the prior one, the real laboratory approach. The facilitation process also helped them to be ready, pre-laboratory questions, and to check what they have learned, the post laboratory questions. In general the advantages are many such as illustrating abstract concepts such as charges and magnetic field, engaging them for active learning, increased interaction and communication. However, it made students busy and some of them were complaining about the tasks such as post-laboratory questions and laboratory reports since the time the semester schedule was too tight because of COVID-19. Many of them were suffering from computer skills and using the simulation. The laboratory technician was busy to support them. Still some of them were confused as they moved from the simulation to the real laboratory even with the symbols of elements of electric circuit. Thus, if it planned to be implemented in colleges, the first thing should be that students should have enough knowledge and skills starting from high schools. Enough number of computers should be presented. And it has to be part of the schedule. Other science course should be given in a similar fashion and students should be aware about the role of simulations in science teaching.

In a similar fashion, the physics teacher educator and laboratory technician in the virtual laboratory group were also asked about their perception regarding the newly implemented laboratory learning environment, its advantages and disadvantages, and comments and suggestions for improvement. The physics teacher educator replied that many times the concepts in electricity and magnetism are abstract and students were challenged to learn these abstract concepts. The new laboratory learning environment (interactive virtual simulation) assisted students to learn these concepts such as charges, flow of current, magnetic field lines and electromagnetic induction phenomena. These times it has been a good alternative in relation to COVID-19 pandemic. The interviewee observed that students were actively engaged in the laboratory activities and were attracted to the phenomena on the computer screen. The particular advantages mentioned by the teacher educator were visualizing abstract concepts, motivating students for learning and work in the laboratory, interaction and communication increased, and were asking questions and support frequently than the conventional approach. According to the interviewee, students were focused on recording data to write report than learning the physics concept in the conventional laboratory. The follow-up of the laboratory technician and teacher educator was also increased.

However, it needed high assistance from the laboratory technician and teacher educator. PSPTs were challenged in using the computer and simulation activities. Shortage of computers was also a challenge. Some students have been focused on unnecessary simulation effects than the physics concept it hold. The advantages mentioned by the physics teacher educator were that the virtual laboratory experimentation enabled them to learn abstract concepts easily, actively participated and engaged in the activities. And, the disadvantages mentioned by the physics teacher educator were computer training and providing computer access need to be done. Additionally, there was no room for practical activities using real materials, some of them did not take it seriously, and unless they are guided most of them were mostly focusing on different aspects of the simulation rather than the concept to be learned behind. The interviewee added that the students' hands-on skill would be deprived of when using virtual laboratory experimentation. The suggestion for future improvement were it has to be combined with real laboratory. The simulation should be used as supportive and warming up activity to the real laboratory. Even if there are no enough equipment, it should be done using hands-on activities that can be done using available materials. In addition, it has to be part of the curriculum.

The laboratory technician replied that a clear difference was observed between the previous and the current laboratory approach, virtual laboratory experimentation. According to the interviewee, it has changed positively the attention given to laboratory. In the convention physics laboratory, students come to the laboratory room to set-up experiments and record data to write a report. There was no as such a discussion on the topic. The laboratory course was often left for the technician by default. In the current approach, students were actively engaged pre-laboratory questions, in the laboratory activities, and post-laboratory questions. They were very interested in their stay in the physics laboratory. In the previous, they were continuously looking for their clock to move out of the laboratory room but in the new approach they run out of time. The particular advantages were illustrating abstract concepts, interest in the laboratory and high interaction, and the support from teacher and laboratory technician increased. The disadvantages were, however, there was no interaction with real materials and they will be challenged when they go to schools. They will be unable to even work with science kits. There would not be enough possibility to be acquainted with real materials other than the college. In most secondary schools, practical work is neglected because of many reasons, like lack of equipment and focus to cover the contents of the subject. In the future, it has to be combined with the real one. Refreshment training on using the simulation need to be done for the teacher, technician, and students need to be done.

4.5.3. Results of laboratory observation

The acquisition of necessary practical skills after conducting an experiment activity was a topic of discussion in the study literature addressing different modes of physics laboratory experimentation. So, the purpose of this observation was to ascertain the degree to which participants in the three study groups acquire the essential practical skills after completing the experiment activity. A laboratory session was observed using a rubric to identify materials and equipment and construct an Ohm's law circuit in order to measure the performance of the participants' laboratory skills. Results for identifying the materials and equipment used to construct the Ohm's law circuit are displayed in Table 4.26.

Table 4.26 *Identifying the materials and equipment used to construct an Ohm's law circuit*

Study Group	Lab Group	Identified None	Identified up to 2	Identified up to 4	Identified up to 6	Identified all materials & equipment	Total score
BEG	BG1				15		15
	BG2				15		15
	BG3					20	20
	BG4					20	20
VEG	VG1					20	20
	VG2				15		15
	VG3			10			10
	VG4					20	20
	VG5					20	20
REG	RG1					20	20
	RG2					20	20
	RG3				15		15
	RG4					20	20
	RG5					20	20

As displayed in Table 4.26, the total score of each laboratory group in the study groups were assessed. Since the objective of the study was to compare groups, average values for each study group were calculated by dividing the total scores for all laboratory groups in each study group by the total number of laboratory groups in each study group. Accordingly, the average scores for each research group on identifying the materials and equipment needed to construct Ohm's law circuit were 17.5, 17 and 19 points out of 20 for the blended, virtual, and real laboratory experiment groups, respectively. Based on this result, participants in the real followed by blended experiment group performed better in terms of material and equipment identification after receiving the intervention.

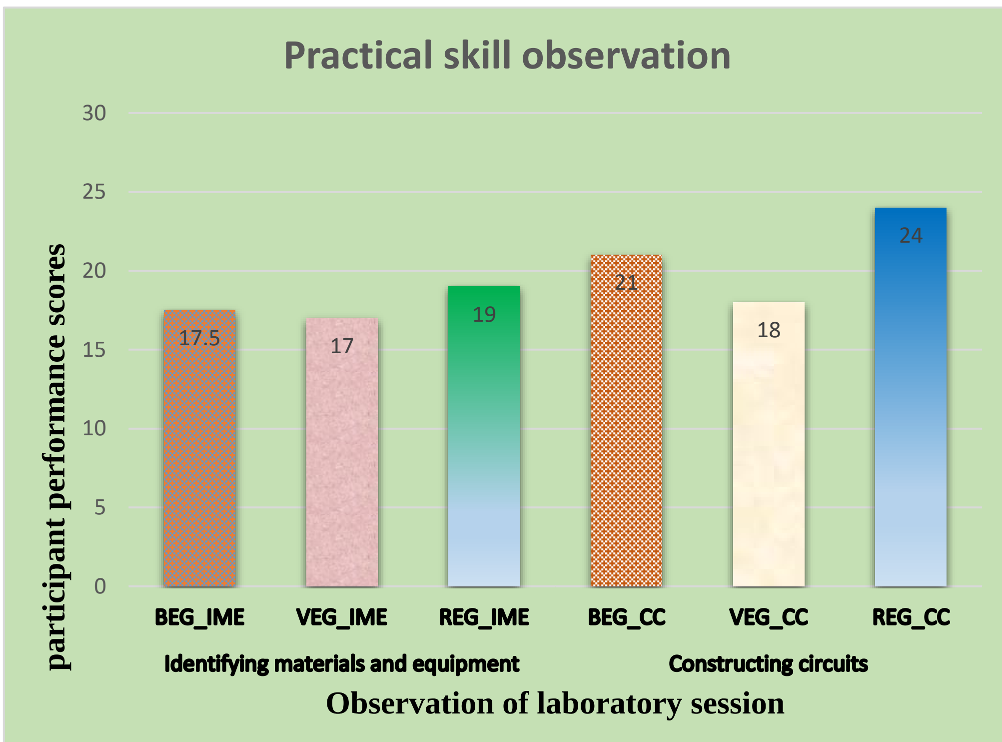
Observing how the participants in each laboratory group of the study group constructed an Ohm's law circuit was the second task that was accomplished during the laboratory session observation. The scores of each laboratory group in each study group for circuit construction are summarized in Table 4.27.

Table 4.27 *Laboratory session observation regarding construction of Ohm's law circuit*

Study Group	Lab Group	Connecting voltmeter properly	Connecting ammeter properly	Connecting properly polarities of measuring devices	Connecting the resistor in series with the source	Open switch after completing the circuit	Total Score
BEG	BG1	6	6	3	6	3	24
	BG2	0	6	0	6	0	12
	BG3	6	6	3	6	3	24
	BG4	6	6	3	6	3	24
VEG	VG1	0	6	3	6	3	18
	VG2	6	6	0	6	0	18
	VG3	0	6	3	6	0	15
	VG4	6	6	0	6	3	21
	VG5	6	6	0	6	0	18
REG	RG1	6	6	3	6	6	27
	RG2	6	6	6	6	3	27
	RG3	0	6	3	6	3	18
	RG4	6	6	6	6	3	27
	RG5	6	6	3	6	3	21

As shown in Table 4.27, each study group of participants who were taught through blended, virtual, and real laboratory experiments, respectively, scored an average of 21, 18, and 24 points out of a maximum 30 for constructing the requested circuit. According to the results, the real experiment group scored the highest followed by the blended experiment group in terms of circuit construction. Figure 4.2 illustrates the average scores for each study group based on the two phase laboratory session observations.

Figure 4.2: *Scores from observation of laboratory session*



Note that: BEG, VEG, and REG stand for blended experiment group, virtual experiment group, and real experiment group, respectively, and IME and CC stand for identifying materials and equipment and constructing circuits, respectively.

As illustrated by Figure 4.2, the real experiment group achieved the highest scores both in identifying materials and equipment and constructing the needed circuit. The two phase observation of a laboratory session yielded the lowest score for the virtual experiment group.

Participants in the blended experiment group received scores that fell between those of the real and virtual experiment groups. According to the results, it can be said that real experiments might have enhanced laboratory material and equipment identification and circuit construction more than blended and virtual experiments.

The findings from both quantitative and qualitative data can be summed up in the manner that is explained below. The gathered data were appropriately registered, a preliminary analysis was conducted, and all relevant assumptions were checked. The data were therefore analyzed using descriptive statistics, One-way ANOVA, post hoc comparisons, paired-sample t-tests, and normalized gains. Thus, the first three research questions were answered using the quantitative data.

The fourth research question was also addressed using data analyzed from semi-structured interviews and classroom observations. The semi-structured interview revealed evidence of how each experimenting mode influenced PSPTs' learning as well as their opinions and suggestions for improvements in the future. In addition, laboratory session observation of Ohm's law revealed the level of material identification and construction of circuits by PSPTs from each group. Participants in the treatment groups generally said that the physics laboratory experimentation used helped their learning, reflected their favorable opinions of PhET, and engaged them in the process. However, the majority of the participants who were interviewed raised issues about problem of access to computers, lack of skills in using computers and PhET simulations, constraint of practice time, and requested for incorporation of PhET in the laboratory course.

In terms of posttest scores on conceptual understanding and attitudes toward physics laboratory experiments, the study's findings generally showed statistically significant mean differences between the treatment and comparison groups. On the other hand, there was no statistically significant difference in the mean posttest results for understanding the nature of science.

The virtual laboratory groups outperformed the blended and real laboratory groups in conceptual understanding test. The blended laboratory groups, on the other hand, did not show a significant improvement when compared to the real laboratory groups, despite having a higher mean gain. It can be stated that pre-service physics teachers gained more conceptual understanding in virtual laboratory experimentation than the comparison group. The paired sample t-test showed that, with the exception of the comparison group, the real laboratory group, the mean of the posttest scores in the virtual and blended groups were significantly greater than the mean of their pretest scores. For PSPTs taught employing virtual, blended, and real physics laboratory experimentation, the calculated normalized Hake's increase in conceptual understanding test scores were 0.221, 0.142, and 0.047, respectively. The computed normalized gain was under low category, in accordance with the interpretation criteria, despite some differences between the three groups.

In terms of understanding of the nature of science, the results revealed no statistically significant difference in mean posttest scores of the treatment and comparison groups. Though not statistically significant, there was a slight mean shift in favor of blended laboratory groups followed by virtual laboratory groups over the comparison group when comparing pretest and posttest VNOS. After being taught with real, virtual, and blended laboratory manipulatives, PSPTs' understanding of NOS was nearly comparable. Furthermore, no significant difference was found between the treatment and comparison groups as a result of the interventions used.

There was a statistically significant difference in mean of posttest scores between comparison and treatment groups in terms of attitude toward laboratory experiments. Using the paired-sample t-test, the treatment groups significantly improved their attitude toward the physics laboratory, while the comparison group showed no significant difference. The Tukey post hoc multiple comparison test showed a statistically significant difference in mean posttest scores of attitude towards physics laboratory between those taught using the blended and real laboratory experimentation group in favor of the blended. However, there was no significant difference in mean between the virtual and real laboratory groups or blended and virtual laboratory groups.

The teacher and the laboratory technician who worked with the blended experiment group conveyed this idea by stating that after students complete a virtual simulation of an experiment, they feel bored in carrying out the real experiment. Despite the fact that it was thought that the blended form of experimentation combined the advantages of virtual and real experimentation, the findings contrasted with the results of many earlier studies. Inevitably, there are differences in the setting, the design, the time spent on the activity, and other factors. The time constraint, the loose atmosphere in laboratory courses, unfamiliarity with the simulations, and unfamiliarity with the inquiry laboratory technique are some reasons why the blended experiment may have made it more difficult for participants to learn.

Participants in the blended group replied in the qualitative data that the blended method gave them the opportunity to work with materials and simulations. They did, however, only have a limited period of time to become proficient with the simulations. Participants still had to learn a new tool as they were required to get acquainted with buttons and moving objects, which they may not have been used to before, even if they received an activity guide to guide them through the simulations step-by-step. Also, it might have been challenging for them to shift from virtual simulations to real experiments and combine the knowledge acquired to understand the concepts.

CHAPTER 5: DISCUSSION and CONCLUSIONS

Introduction

This study was to examine how effectively the blended mode of physics laboratory experiments influenced teacher education college students' conceptual understanding, understanding of the nature of science, and attitude toward physics laboratories. In chapter four of this dissertation, the quantitative and qualitative results have been presented, with the qualitative data assisting the quantitative one. That is, the qualitative data augments the conclusions drawn from the quantitative data gathered. These two types of data are merged in this part to establish a coordinated picture of the problem being studied. The conclusions of the study, recommendations, and educational implications are then addressed.

5.1. Discussion

Based on the outcome variables assessed, there were statistically significant differences in conceptual understanding posttest scores between the treatment and comparison groups in favor of the virtual one. In addition, a significant difference in attitude toward the laboratory was found between the treatment and comparison groups in favor of blended experimentation. However, there was no statistically significant difference between the treatment and comparison groups in terms of students' understanding of the nature of science. The effectiveness of the blended mode of laboratory experimentation on each of the variables assessed is discussed in detail in the sections that follow. In other words, the effectiveness of the blended mode of laboratory experimentation in physics is compared to that of virtual and real ones, and a discussion is held on each of the outcome variables in relation to previous studies.

5.1.1 Conceptual understanding

When comparing the pretest and posttest scores of the comparison and treatment groups, a paired-samples t-test was used as one method of quantitative data analysis. This analysis was done to determine whether preservice physics teachers' conceptual understanding was improved by the use of blended, virtual, and real modes of laboratory experimentation. The results revealed that the treatment groups, virtual and blended modes of experimentation, significantly improved the conceptual understanding of pre-service physics teachers on electricity and magnetism concepts covered in the Experimental Physics course. However, calculating Hake's normalized gain revealed that the improvement category in the treatment groups was small.

There was no significant gain in conceptual understanding in the comparison group between the pretest and the posttest, despite a slight mean difference. This could probably be due to the low achievement of students in lower grades in general and in physics in particular, because a majority of PSPTs enrolled in CTEs are those who were unable to enroll in universities. According to the one-way ANOVA analysis, the mean posttest score of the conceptual understanding test among PSPTs taught using real, virtual, and blended physics laboratory experimentation was statistically significant. The Tukey post hoc comparison test showed that there was a significant mean difference in conceptual understanding test scores between VEG and BEG and VEG and REG, but no significant difference in mean scores between BEG and REG.

With regard to the results of the current study, previous studies reveal both consistent and inconsistent results. For the purposes of this discussion, we can divide the comparisons into three categories to see if the results were consistent with or contradictory to other studies: blended with virtual, blended with real, and virtual with real.

A systematic review of studies on chemistry laboratory education was undertaken by Chan et al. (2021), and the results were compared between combination (virtual and hands-on) laboratories with virtual only laboratories and hands-on laboratories only. The results revealed that using virtual and hands-on laboratories combined resulted in positive improvements in 1 study and equal outcomes in 1 other study using solely virtual laboratories. When compared to a hands-on laboratory, the virtual and hands-on laboratory combination showed positive improvements in 5 studies and was equivalent in 2 studies. On the one hand, it is challenging to determine from the results whether the improvement was caused by the media or the instructional approaches because different instructional strategies were used in these comparisons. Besides that, the implementation of the instructional materials was not adequately explained.

The findings of the study by Olympiou and Zacharia (2010) are partly consistent with the results of the present study. The authors compared how experimentation with virtual, real, real-virtual combinations, and virtual-real combinations affected preservice elementary school teachers' understanding of scientific topics related to heat and temperature. According to the findings, all four types of experimentation were equally effective in helping students develop their conceptual understanding of heat and temperature. That is, it was found that using the real and the virtual separately and in combination had similar effects on improving conceptual understanding. Unfortunately, they only used four conceptual tests. Zacharia et al. (2008) used a similar design but conducted quantitative and qualitative analyses of the data gathered from conceptual testing. Results remained consistent. The authors of both studies came to the conclusion that, when grounded in the physics by inquiry framework and in full control of all the factors that affect the learning process and outcomes, the use of either real, virtual, or their combinations could provide equally engaging experiences that improve students' understanding of concepts. The funny thing is that in research they conducted in the years that followed, which are mentioned later in this section, these writers come up with entirely different conclusions.

The current study contradicted many of the findings of a group of studies comparing real, virtual, and blended laboratory experiments. For example, a study comparing the effects of real, virtual, and blended laboratory experiments on undergraduate students' learning of mechanics and ideal gas law was conducted (Darrah et al., 2014). The data collection instruments used were laboratory quizzes, laboratory reports, and tests, and the results revealed that there were no differences in the learning outcomes of the groups.

Other studies found that blended laboratory significantly improved students' conceptual understanding of electricity concepts (Gumilar et al., 2019; Zacharia & Michael, 2016; Farrokhnia & Esmailpour, 2010) and light and color concepts (Olympiou & Zacharia, 2014; Olympiou & Zacharia, 2012). The reported positive outcomes also depend on the analyzed outcome variables. For instance, the study by Farrokhnia and Esmailpour (2010) have found that when there was a statistically significant difference in conceptual understanding between the groups, no difference was observed when laboratory circuit skills were measured. This result also clarifies the existence of inconsistent results across learning outcomes.

Regardless of discipline or study participants, there are studies whose findings are consistent with the current one. It is consistent, for example, with a quasi-experimental study comparing blended, simulation, and lecture-based methods on midwives' performance in medical issues during pregnancy (Tabatabaeian et al., 2018). The results showed that the mean performance score in the simulation group was significantly higher than the mean performance scores in the blended and lecture groups, and it was higher in the blended group than in the lecture-based group. The increased outcome of the simulation group was attributed to learner activation, implying that a student-centered education strategy can increase learner satisfaction and accelerate learning. Given the fact that it was conducted on medical issues and in a different domain, this study employed quasi-experimental design and provides insights into the current study.

Another study comparing the efficacy of teaching and testing using traditional and virtual microscopy was conducted, which could provide important insights into the current study's findings (Scoville & Buskirk, 2007). It compared four groups: a comparison group in which learning and testing occurred face to face; a fully online group; a blended group in which learning occurred virtually but the practical examination occurred face to face; and another blended group in which learning occurred face-to-face but testing occurred virtually. The results indicated no significant differences in testing groups, learning groups, or interaction effects. But, the study was carried out using a completely random design based on participants' prior achievement.

Another quasi-experimental study on the acquisition of the English language found no appreciable differences between teachers who attended blended instruction and those who received face-to-face instruction (Kocoglu et al., 2011). On the other hand, a quasi-experimental study comparing the impact of inquiry-based blended learning material with traditional learning activities found that students' achievement was much higher with these materials than with the traditional materials (Motlan et al., 2016).

All we can assert is that there are no consistent results because there are no uniform methods for conducting studies. Earlier studies comparing real and virtual appeared to recommend replacing real with virtual, but the trend has since shifted. Similarly, after conducting blended learning research, authors still recommend further research on blended mode of laboratory education. Researchers recommended additional research after reviewing a number of studies to address important concerns about mixed results (Brinson, 2015) and to propose frameworks and provide additional insights for future research (Wörner et al., 2022).

In the current study, too, PSPTs in the interactive simulation group might be more motivated whereas those in the blended group were frustrated with multiple tasks at a time as it was evidenced during the interview. Some of the PSPTs interviewed, physics teachers and laboratory technicians in the blended group uncovered that they were too busy to complete the laboratory tasks in time. For this reason, PSPTs in this virtual simulation group might be beneficial as there was only one mode of experimentation. Since there are multiple tasks that need to be accomplished, further time, materials and instructional strategies are required in the blended mode of experimentation. In line with this, researchers claimed that blended learning will be effective if it is well-planned, organized, require appropriate attitudes, necessitates additional time to complete tasks, additional resources, and facilities as it is complex because of various modalities (Lalima & Dangwal, 2017; Guy & Lownes-Jackson, 2015). Scholars claimed a similar idea that substantiates this idea stating that if students are adequately prepared at the start both conceptually and procedurally, they will benefit effectively from practical laboratory classes (Gregory & Trapani, 2012). This was a survey study on a blended learning approach to laboratory preparation and it was found that students who were well equipped for laboratory classes are more likely to be able acquire laboratory skills and obtain the most value from the laboratory learning environment. According to other studies, in order to achieve the best results in blended learning, it is important to identify the different student learning preferences and use the best possible blend of learning methods (Tambunan et al., 2020). It can be deduced that in order to get the most out of the blended learning method, a variety of factors including contexts, instructional strategies, time-on-task, instructional materials, attitude towards computers, and learning preferences of students must be identified, and instructional materials and activities must be designed accordingly.

That is why some authors claimed that the effectiveness of blended learning originates not because of the media per se rather on the additional time on task, additional instructional resources and innovative instructional strategies employed (Means et al., 2009). In the current study, all the three groups were similar in the time allotted, curriculum material and instructional strategy except the type of manipulative utilized. The blended group did not receive any additional benefits other than using the two manipulatives. This might have created burden on the learning of participants. But, the experimentation method and instructional strategy used were unfamiliar to the participants. It may be deduced from review studies by Wörner et al. (2022) and Zacharia (2015), as well as a doctoral study by Marino (2018), that participants' prior knowledge and experience have an impact on the efficacy of different modes of laboratory experimentations. For instance, Marino (2018) reported that high-achieving students benefitted more from virtual laboratories than from hands-on laboratories, whereas there was no difference for low-achieving students. Because of this, scholars claimed that the issues of how to effectively activate prior knowledge before beginning the experiments and how to design inquiry tasks utilizing VE and RE such that they enabled incremental learning provide to be addressed (Wörner et al., 2022).

Regarding students perceptions, a study was undertaken to investigate students' perceptions of whether blended laboratory courses assist them tackle the difficulties they face, and it was found that students' abilities in self-learning, understanding, and problem solving improved (Chen, et al., 2020). According to the qualitative data analysis, students were interested in the blended and virtual experiments in the current study. But, they raised concerns with the intervention process, a lack of time, and a shortage of experience with computers and software.

There are also debating results in the literature when comparing conceptual understanding obtained from virtual and real manipulatives in physics laboratory experimentation. While many studies emphasize primarily their positive outcomes, evidence on the efficacy of simulations for science learning is inconsistent (Oser, 2013). Studies which are consistent with the findings of the present study comparing conceptual understanding of students taught using virtual and real laboratory group are many. For example, the study by Finkelstein, et al. (2005) to examine the effects of real and PhET interactive simulations on the topics of direct current circuit in introductory physics course. The results revealed that students who were taught using interactive simulations outperformed their counterparts on mastery of concepts and skills in assembling real circuit. However, the authors did not suggest that interactive simulations inevitably enhance conceptual learning and ensure capability with real laboratories. They rather cautioned that the virtual environment would be productive than the real one when it is properly designed and possess explicit goals.

Furthermore, Zacharia (2007) conducted a study to compare the effectiveness of RE and VE, and the results revealed that the group using virtual experimentation gained significantly better conceptual understanding than the RE group. On the other hand, the findings of a study revealed that physical laboratories improve secondary school students' geographical achievement, despite the fact that virtual laboratories could be used to supplement physical laboratories (Usman et al., 2019). Physical laboratory environments, according to the authors, should promote and encourage social interaction, active learning, learning by doing, and learning by experience, among other benefits.

A study conducted to compare the effects of hands-on, virtual and combined laboratory environments revealed that the combined ones (virtual-real or real-virtual) have brought significantly better conceptual knowledge to grade 7th students on the topics of electricity. Whereas, either virtual or hands-on laboratory learning environments were equally effective in developing inquiry skills of students across the investigated combinations (Kapici et al., 2019). On another article, these authors reported that there was no significant difference in attitudinal improvement of students taught using hands-on, virtual, and their combination despite descriptive values showed that virtual were more effective than other learning environments (Kapici et al., 2020). Another study found that when heat and temperature were taught using blended learning techniques in a one-group pretest-posttest design, there was an increase in conceptual understanding gain (Supriana et al., 2020). However, the blending concept utilized here was to combine face-to-face instruction with online quizzes and discussions. Other limitations of this study included the one group pretest-posttest design and how the blended design was implemented.

Another experimental study compared the effects of three laboratory learning environments, namely laboratory equipment, simulation, and their combination, on students' understanding of simple electricity (Jaakkola & Nurmi, 2008). The findings revealed that overall pretest-posttest development was significant across all three modes of laboratory experimentation. Posttest score comparisons showed that students who worked in the combination setting outperformed the rest of the group in terms of learning outcomes. However, no statistical differences were found between simulation and real laboratory environments. The simulation was used in the combination group to allow students to discover theoretical principles of simple electricity and then transfer to real circuits for each activity. It was not done by selecting affordances of laboratory objectives of experiment as other researchers did, for example (Zacharia et al., 2012; Zacharia & Olympiou, 2011). Another study in which same authors involved was conducted to compare RE alone, VE alone, VE preceding RE combination, Re preceding VE combination, and traditional laboratory instruction (Zacharia & Olympiou, 2011). Students in the treatment groups scored significantly better on posttests than students in the comparison group across all tests. The pairwise comparisons, however, did not show any evidence of a significant difference in the posttest scores of the treatment group students across all tests, suggesting that all treatment conditions were equally successful in fostering students' understanding of these ideas. These results demonstrated that, even when carried out by the same authors, blended laboratory investigations give contradictory outcomes.

It is not reasonable to attribute the effects of different laboratory learning environments to the manipulatives used; rather, previous studies have revealed that the instructional strategy used has an effect (Jaakkola et al.; 2011). The authors compared simulation conditions with implicit instruction, simulation conditions with explicit instruction, combined conditions with implicit instruction, and combined conditions with explicit instruction. This time, the combination condition was developed by running a simulation together with real circuits. The findings revealed that when students received combined and mediated by implicit instruction, their overall gain from pretest to posttest was higher. The study implied that when using real circuits and simulation in parallel, students appear to learn more effectively when given opportunities to learn the material than when the procedure is more structured. Thus, in addition to the use of various manipulatives and combinations, the manner in which instruction is mediated has an effect on students' learning.

In the current study, the blended laboratory learning environment was found to be as effective as the real laboratory but significantly less effective than the PhET interactive simulations in developing conceptual understanding of PSPTs. The identified result was somewhat difficult to explain and relate to prior studies, but it can provide implications if we examine the circumstances in which and how other studies were carried out. Not only the current study, but other studies conducted by the same scholars in different domains, participants, and learning outcomes produced widely divergent results. A study, for example, compared the effectiveness of real only, virtual only, real preceding virtual, virtual preceding real, and traditional laboratory on undergraduate students' conceptual learning of heat and temperature (Zacharia & Olympiou, 2011). According to the findings, all four laboratory learning environments were equally effective in improving conceptual understanding of heat and temperature, but they outperformed the comparison group. The authors came to the conclusion that it is the manipulation rather than physicality that is essential. However, the same authors investigated the effectiveness of a blended combination of real and virtual manipulatives on the conceptual understanding of light and color topics in undergraduate students (Olympiou & Zacharia, 2012). The findings are highly controversial, and the challenge remains debatable, but it is undeniable that any effort may provide an insight for future research.

When such fallacies exist, it is critical to thoroughly investigate all of the possible conditions under which the studies were conducted. The level of participants, their prior experience, the domain of investigation, the study design, instructional materials and strategies used in the intervention, learning outcomes measured, data gathering instruments, investigator factors, and others, for example, could all be sources of variation in the results. Authors who reported successful effects concerning learning outcomes of blended laboratory learning, for example, contended that well-designed combinations of virtual and real laboratory learning result in greater gains in conceptual understanding when in comparison to one type of laboratory alone (Zacharia & Michael, 2016; Olympiou & Zacharia, 2012; Jaakkola & Nurmi, 2008).

There is no consensus framework for guiding the development of useful instructional material, activity design, and instructional strategy for blended laboratory learning. Because blended learning is still in its early stages, there is no clear pedagogy for it in general, and for blended laboratory learning in particular (Olympiou & Zacharia, 2012).

When compared to studies yielding opposing results, those yielding favorable results were not directly related to the type of manipulatives used. There are evidences, but this could be due to the treatment group's special emphasis, extra time spent on task, the influence of the teacher implementing the intervention, the availability of additional learning resources, the use of various innovative approaches, and so on. Furthermore, inconsistencies in terminology usage, the absence of a general framework, and the inclusion of multiple definitions for blended learning obscure the model. Many studies, however, did not reveal the specific nature of the procedures used to conduct the study. Many studies failed to explain the context for the blended learning research. Before we get there, let's take a look at some of the previous publications on the subject. Many research studies have stated that the type of instructional strategy used, particularly the inquiry method, determines the effectiveness of the manipulative used. Aside from the issue of using various laboratory learning environments, the most essential element in science teaching success is the design of instruction to ensure that students benefit from laboratories (De Jong et al., 2013). According to the authors, designing laboratories that take advantage of impactful guidance necessitates interdisciplinary teams comprised of domain experts, technologists, and learning scientists, with such groups typically refining their designs based on testing in instructional settings.

The results of this study are in agreement with those reported for virtual laboratory experimentation, but they differ from those reported for blended physics laboratory experimentation. In this study, the instructional materials were PhET simulations of experimental activities from the Experimental Physics II course.

PhET simulations can considerably improve students' conceptual grasp of physics and can be implemented into a variety of active learning teaching contexts, according to the reviewed research (Banda & Nzabahimana, 2021). Inquiry-based activities, virtual laboratory experimentation, problem-based learning activities, and supportive learning activities are among the instructional methodologies advocated by the authors for employing PhET simulations to promote conceptual understanding. Additionally, the authors suggested that there is a pressing need for studies to determine the influence of collaborative and group learning techniques supported by PhET simulations on improving understanding of concepts in physics. As this area of education is currently understudied, they also noted the need for additional study on the effects of PhET simulation-based learning on students' cognitive engagement and conceptual understanding. Therefore, we can conclude that there exist complex challenges with PhET simulation's effectiveness in improving conceptual understanding of physics.

According to scholars, these blended environments frequently included extra learning time and educational materials that students did not have access to comparison conditions (Means et al., 2009). This study suggests that the beneficial effects of blended approach should not be primarily attributed to the media. The authors reported that from the results of the 50 individual research effects, 11 were statistically significant in favor of the online or blended learning condition, while three contrasts revealed an effect in favor of the conventional face-to-face condition. The authors also noted that many studies did not make an effort to compare all of the curriculum components, pedagogical practices, and learning durations in the treatment and comparison conditions. That means, there might be extra benefits in the treatment groups in the blended learning approach apart from the different in the mode of experimentation. As a result, the observed benefit for blended settings may reflect variations in content, learning time, and pedagogy rather than the media utilized per se. The authors concluded after reviewing over 50 articles on online, blended, and face-to-face instruction that many had significant effects supporting blended learning, while others had significant effects supporting face-to-face instruction than blended learning environments.

The results of studies utilizing solely online and blended environments, according to the authors, shed some suspicion on the meta-analysis result of increased impact sizes for investigations combining face-to-face and online components. The disagreement of the two sets of studies' conclusions emphasizes the need of recognizing practice factors confounding in most investigations. Blended learning studies typically include increased learning time, more instructional resources, and curriculum components that enhance student involvement. This confounding raises the potential that one or more of these other implementation variables, rather than the blending of offline and online media per se, are to account for the meta- analysis's favorable results for blended learning. Hence, the reasons for the discrepancies between the findings of earlier studies and those of the current study may be related to the aforementioned factors.

The authors also claimed that many studies contrasting blended learning with other types of instruction had weaknesses including small number of samples, inadequate efforts to report rates of retention for students in the circumstances being compared, and possible bias due to the authors' dual roles as teachers and experimenters. However, the authors claimed that blended learning environments had strong support though it was the combination of elements such as additional learning time, additional resources, differed instructional strategy and investigators bias that might have produced the observed learning advantage (Means et al., 2009).

These days there is a need to use ICT in education by expanding and improving ICT infrastructure at all levels of the education system including CTEs (MOE, 2015) and understanding how to use computers and design high quality technology-enhanced lessons were identified as cross cutting issue (Teferra, et al., 2018). Integrating ICT in the education system in general and science and mathematics education in particular is therefore the concern of the government. Science laboratory in general and physics laboratory in particular will benefit from the opportunities of ICT supported instruction. It is therefore important to examine their effectiveness including the perception of students and teachers before large scale implementation. It was a recent phenomenon that how the plasma-based education in Ethiopia was facing challenges beyond what the government has intended. Studies has pointed out that the plasma-based instruction has widened the educational status gap (Getnet, 2008) and its philosophy was beyond classroom teachers' philosophy of teaching and the students' philosophy of learning (Berhanu, 2013). This implies that appropriate readiness and familiarization of new innovation is mandatory before large scale implementation. For instance, Gumilar et al. (2019) advised that any researcher conducting a study including BE in an inquiry context should use care while teaching students in the setting of an inquiry experiment. The participants must become familiar with the inquiry experiment because when they lack knowledge and expertise, the findings of the study will be biased as a result.

Thus, the current study is expected to bring about two essential contributions. Firstly, by addressing the reasons for inconsistencies, it strengthens the existing body of literature, which has produced contradicting results about the effects of laboratory experiments in the blended mode on conceptual understanding. Second, it provides insights into how pre-service physics teachers, physics teacher educators, and laboratory technicians perceive these technology-enhanced physics laboratory experiments.

5.1.2 Understanding of the nature of science

The purpose of utilizing understanding of the nature of science as a learning outcome to investigate efficacy of different modes of laboratory experimentation was that the VNOS that science teachers have directly impacts their teaching practice and behavior. Actually, it is not only for science teachers NOS is also an essential element of scientific literacy. Thus, it is very important to examine efficacy of the different laboratory learning environments on learning understanding of the nature of science.

According to the data analysis, there was not a statistically significant difference between the pretest VNOS scores before the intervention. Similarly, post-intervention assessments of pre-service physics teachers' views on the nature of science showed no significant mean differences between the three groups. In addition, neither the treatment groups nor the comparison group showed significant improvement in their conceptions of NOS because of the interventions employed. That is, pre-service physics teachers who were taught using all three modes of laboratory experimentations showed no significant change in their understanding of nature of science when compared before and after the intervention.

The results of this study revealed that although there was very little development in posttest VNOS scores, significance difference was not observed. This means that all the three modes of experimentations have not been able to significantly improve understanding of the nature of science aspects. There was no statistically significant difference between the treatment and comparison groups in terms of the conceptions of the aspects of the nature of science. In other words, understanding of the nature of science aspects was unaltered by the three types of laboratory experiments. There was a slight difference in mean between the pretest and posttest scores, as well as between the comparison and treatment groups, favoring the posttest and the treatments, respectively, even if it was not statistically significant. This finding is consistent with many studies that have been done on how participants perceive various aspects of nature of science after receiving instruction.

The study's results demonstrated the majority of what had been reported regarding pre-service physics teacher' understanding of science in the literature. For instance, Hinkhouse (2013) investigated blended learning on nature of science. The author reported that there was no significant difference between the pretest and posttest responses of treatment and comparison groups implying that the attitudes and opinions of participants regarding the nature of science persisted unaffected. In the curriculum content used, there were no explicit nature of science aspects, role of science or science processes which is similar to the current instructional materials used, which was Experimental Physics II laboratory course. The nature of science aspects were not explicit goals of the physics laboratory course.

As a result, it was not surprising that pre-service physics teachers' views about the nature of science remained unchanged, as reported by many of previous studies done on comparing explicit and implicit instruction of NOS aspects (Izci, 2017; Sardag, et al., 2014; Khishfe & Abd-El-Khalick, 2002; Abd-El-Khalick & Lederman, 2000). These authors claimed that, as opposed to merely engaging in scientific pursuits like observation and experimentation, students might be educated about NOS and its components via an explicit-reflective method. For example, many students believe that the scientific conclusions drawn regarding the working principle of nature are final (Abate et al., 2021). These views could not be easily changed in a semester course.

The qualitative PSPT responses showed there were no significant differences in terms of observations and inferences, scientific theories and laws, scientific techniques, and social and cultural embeddedness between the treatment and comparison groups. However, the PSPTs that responded to the NOS with categories of naive, mixed, and informed views showed significant variations between the groups in terms of the imagination and creativity of scientists as well as the tentativeness of scientific knowledge. Particularly, PSPTs who received instructions through virtual physics experiments had more informed opinions about the tentativeness of scientific knowledge and the imagination and creativity of scientists. These findings are consistent with prior studies (Mesci & Schwartz, 2017; Findlay & Souter, 2008). For instance, according to Mesci and Schwartz (2017), the majority of students showed a significant improvement in their understanding of nearly all components of the NOS, while other students still had difficulty with specific aspects of the NOS even after taking a semester-long science inquiry NOS course. When evaluated qualitatively, PSPTs may still have naïve ideas while having a high level of agreement and favorable opinions regarding all or some components of NOS (Findlay & Souter, 2008). By the end of the intervention period, which was a semester, some other authors reported that almost all students had improved their understanding of NOS (Mesci & Schwartz, 2017; Lederman, 2007). However, there were differences in the teaching methods and instructional materials used. For instance, in a study by Mesci and Schwartz (2017), a Scientific Inquiry course was used to examine pre-service teachers' perceptions of NOS and identify the components that the participants found challenging. According to scholars, instructional, motivational, and sociocultural variables may have an impact on whether or not there are changing opinions on different aspects of NOS (Abd-El-Khalick & Akerson, 2004).

Pre-service science teachers are encouraged to take additional scientific courses, actively engage in laboratory experiments, and participate in other activities in order to enhance their understanding of the nature of science (McComas, 2006). Other scholars claimed that instructional techniques may not help all students reach the expected level in all aspects of NOS (Mesci & Schwartz, 2017). Other scholars claimed that students can be provided with a vivid area that can engage them for learning rather than a ready-made activity that is created by others. According to the author, an ordinary physics teaching status quo could be turned into a learning situation that promotes NOS learning in the process (Hansson & Leden, 2016). The results of the current study, thus, revealed that neither the inquiry laboratory activities nor the technology-enhanced laboratory learning environments altered NOS views. This may lead us to the studies that advocate for the explicit inclusion of NOS aspects and mediate them with innovative instructional strategies (Etkina, 2015; Hodson, 2014).

NOS aspects were not clearly identified in the laboratory course used as curriculum material in the current study. This means that PSPTs were expected to learn about scientific skills such as experimentation, observation and other related skills in an implicit manner. According to studies, no significant difference was detected among treatment and comparison groups based on modes of experimentation. However, a significant mean difference was reported on other learning outcomes in physics, such as conceptual understanding and practical skills, in favor of blended experimentation followed by virtual rather than real mode of experimentation.

The implication for us is that understanding of the nature of science can be enhanced more effectively when components of NOS are incorporated and expressed explicitly rather than implicitly in laboratory activities. The findings of this study confirm those of earlier studies which suggested that explicit and reflective training regarding NOS was beneficial (Hinkhouse, 2013;

Khishfe & Abd-El-Khalick, 2002). Furthermore, studies that support virtual and blended experiments examined the learning outcomes related to understanding of the topic, which is usually an extensively measured dependent variable (Brinson, 2015). There are either no or few study materials available on the efficacy of different laboratory experimentation methods aimed at specific elements of understanding the nature of science (Olympiou & Zacharia, 2012).

It may be concluded from the results of the current study that the intervention had minimal impact on the participants' prior conceptions of NOS. The findings of this study generally concur with those of earlier ones. The majority of the studies the researcher examined in investigating the change in implicit or explicit NOS in preservice physics teachers were carried out on theoretical course materials. In the current study, three different modes of experimentation were used in an experimental course to compare how well these helped students learn about understanding the NOS as an outcome of learning. In a study on blended approach in high school science courses, Hinkhouse (2013) found that students' opinions about NOS did not change. The author and other researchers recommended that providing explicit instruction about NOS elements would alter participants' conceptions of NOS (Hinkhouse, 2013; Abd-El-Khalick, 2005; Abd-El-Khalick & Lederman, 2000). There is evidence, however, that completing an explicit course alone won't give students a complete comprehension of the NOS (Shallow & Tadese, 2021). The authors argued that even though participants had either undergone explicit or implicit NOS courses, they still maintained naive views about many elements of NOS.

Studies have documented how NOS viewpoints changed as a result of treatments. For instance, following the teaching of a semester-long science methods course, pre-service science teachers' views about NOS had significantly changed to reflect more contemporary views (Shim et al., 2010). Of course, there are scholars who claimed that one-size-fits-all approach is not acceptable in enhancing scientific literacy in which understanding of the nature of science is the fundamental component (Glaze, 2018). The author suggested different alternatives, such as changing the conventional way of teaching laboratory experiments to an inquiry approach, using technology to actively engage students, and purposefully adding NOS elements. Still other scholars found that teaching pre-service physics teachers about the history of science or physics improved their views of how scientists develop scientific knowledge (Tanel, 2013).

Others related teachers' views of the nature of science to their own epistemological beliefs (Lederman et al., 2002; Lederman, 1992). Many authors made the claim as a result of this that preservice teachers who took courses in constructivist methodology, educational psychology, learning theories, the foundations of education, and related subjects showed development in their epistemological beliefs, which in turn impacts their views of the NOS (Tanel, 2013; Chai et al., 2009). From prior studies, it can be deduced that there are a variety of results on how to improve one's understanding of the nature of science. NOS components were not specifically addressed in the teaching material used in this study, but it was implicitly expected that certain skills would be gained. All of this has shown that there are many research results and recommendations for enhancing understanding of NOS. Addressing a wide range of literature review and designing appropriate mechanisms that match to the context can be a solution. The current study has assured that using technology-enhanced laboratory environments did not alter significantly previously held views of NOS at least on the studied PSPTs.

5.1.3. Attitude towards physics laboratory

It is obvious that physics laboratory experiments are crucial learning environments to nurture a positive attitude and motivate pre-service physics teachers to study physics. As a result, the attitude of PSPTs' towards physics laboratory play a vital role in learning physics. This is because positive attitudes toward physics and the laboratory experiments can stimulate students and increase achievement in learning whereas negative attitudes make learning rather difficult. It has been assumed that measuring PSPTs' attitudes towards physics laboratory can contribute to examining how the intervention impacts their learning and their responses. It was with this understanding that attitude towards physics laboratory has become one of the learning outcomes measured to examine the efficacy of blended mode of physics laboratory experimentation.

In a physics laboratory experiment course given by CTEs, the attitude towards physics laboratory questionnaire was given twice in a semester, before and after intervention. To achieve this, descriptive statistics, a paired-sample t-test, and a one-way ANOVA were used to assess the data that had been gathered. The participants in both the treatment and comparison groups shared common attributes, including having successfully completed the laboratory course and developing favorable attitudes toward their respective laboratory learning environments.

The mean scores from the pretest to the posttest varied across all of the participating groups. The findings of the paired-sample t-test indicated that these changes were statistically significant for the blended and virtual laboratory groups but not for the comparison group. Pre-service physics teachers who were participants in the comparison and treatment groups showed positive attitudes both before and after the interventions. The attitudes toward physics laboratory experiments between the groups following the intervention showed a significant difference in mean, according to results obtained by one-way ANOVA analysis. The significant differences between the comparison and treatment groups indicated that there were variations in the efficacy of the different modes of laboratory experiments. The Tukey post hoc comparison analysis showed that although there was an observed mean difference among all three groups, the difference only existed between blended and real and not in the other combinations. In other words, there was no significant difference between the mean scores for the blended and virtual laboratory groups or those for the real and virtual laboratory groups. It may be concluded that PSPTs who were taught using blended modes of physics experimentation exhibited the most positive attitude shift regarding physics laboratory experiments.

In fact, after intervention, all of the BEG, VEG, and REG posttest scores were increased. Pretest and posttest results, which were both more than 4 on a 5-point Likert scale, indicated that pre-service physics teachers had a relatively favorable attitude toward physics laboratories. In contrast to the real laboratory groups, PSPTs in the blended and virtual groups showed a significant improvement in their attitude toward physics laboratory between the pretest and posttest. The PSPT posttest scores in BEG were higher than those in VEG, which were higher also than those in REG.

This result is in disagreement with some previous studies (Saputra et al., 2020). The authors conducted a quantitative survey study to identify the attitudes of pre-service physics teachers towards the physics laboratory experiments. The overall result showed that PSPTs had a negative attitude towards physics laboratory activities, which was caused by a verification-type design that did not help them improve their understanding or acquire necessary skills. Another study on the effect of virtual laboratories on students' attitudes toward physics in the domain of direct current electric circuits was conducted through a randomized quasi-experiment design (Faour & Ayoubi, 2018). The outcome showed that there was no significant difference in the attitudes of students toward physics between the virtual experiment group and the real experiment group. In this study, the comparison group was taught using interactive demonstrations using real experiments, whereas the treatment group received instruction using virtual experiments using PhET interactive simulations. Hence, it differed from the current study, at least in terms of design and implementation strategy.

The findings of this current study are consistent with those of previous studies. For instance, studies combining virtual and real research laboratory on university students' affective states, such as attitudes and interest toward science topics, revealed that the combined experiments caused the students to achieve positive affective states (Hurtado-Bermúdez & Romero-Abrio, 2020). Similar to this, the impact of laboratory experiments on the efficiency of physics learning was investigated, and the findings showed that students' developed favorable attitude toward the physics laboratory (Antwi et al., 2021). The positive attitude toward the physics laboratory in all three groups studied may be attributed to the guided inquiry-based learning method. This is because the guided inquiry instructional strategy utilized might helped the participants to more discussion and reflections (Saputra et al., 2020; Bittinger, 2015). In contrast, a study on pre-service physics teachers' attitudes on physics laboratories showed a negative attitude toward physics laboratories due to the verification kind of design (Saputra et al., 2020). The negative result of the study might be attributed to the instructional strategy employed.

In contrast to exclusively virtual and real experiments, blended experiments in the current study enhanced PSPTs' attitudes towards the physics laboratory, but earlier research had shown mixed effects. The results of a study that looked into blended approach in secondary school science classes showed that there was no significant different in the attitudes of the students between the blended and comparison groups on the posttest measured (Hinkhouse, 2013) though the blending was designed using face-to-face and online modalities. The author also noted that neither approach of conducting laboratory experiments had a significant effect on students' attitudes toward science.

In contrast, Alneyadi (2019) showed that one of the outcome variables measured that participants showed substantial improvement in was attitude towards physics laboratory. Nonetheless, focus group with structured interviews were utilized to gather data for the study to examine science teachers' views on students' attitudes toward laboratories.

Although some scholars, such as Chen et al. (2014), have claimed that virtual laboratories can be just as effective as real laboratories, they have also cautioned educators to be aware of the possibility that using virtual laboratories could encourage students to mindlessly design and carry out experiments. According to the authors' findings, real experiment group students had slightly more positive attitudes toward laboratories than virtual experiment group students on Boyle' law. Besides, students reported that they did not find virtual laboratories to be as entertaining as real laboratories and that these did not make a lasting impact in contrast to real laboratories. However, the teacher for both classes was the same, and the teacher occasionally used simulations to illustrate physics concepts during lectures. The data gathering tool for the attitude outcome variable was using post-laboratory interviews with 8 students from each of the two groups out the 68 participants.

In a recent study, the effectiveness of three different laboratory experiments (blended, virtual, and hands-on) on upper primary school students' attitudes towards science was studied, and the results showed that there was no statistically significant difference in attitudinal development between the treatment and comparison groups (Kapici et al., 2020), which is against the results of the current study. The authors reported that the descriptive data revealed that virtual laboratories were more useful than hands-on laboratories for attitudinal change. But, based on the descriptive statistics of the current study, PSPTs in the blended laboratory group had a greater attitudinal change in the posttest scores than the virtual laboratory group, which again was higher than the real experiment group. In the current study, the PSPTs in blended and virtual laboratory groups seemed to have a superior alternative to understanding abstract concepts in comparison to their prior experiences. However, further research in comparable settings is required to address these discrepancies.

In contrast to solely virtual and real activities, the blended experiments in the current study enhanced PSPTs' attitudes towards physics laboratory experiments, whereas past studies had conflicting results. For instance, based on a review of numerous publications, Brinson (2015) found that students' perceptions, preferences, and accomplishments of educational learning outcomes for various types of laboratory experiments were not consistent. This might be because of how blended and virtual activities are developed and implemented, as well as how participants and teachers are familiar with instructional strategies (Gumilar et al., 2019).

Also, one should be aware that virtual laboratories have become an important supplement to or alternative to hands-on laboratories. However, how well a course integrates new technologies as well as social factors and student motivation may determine how well these laboratories assist science teaching (Corter et al., 2011). The majority of the indicators of pre-service teachers' attitudes toward the physics laboratory received negative responses in a quantitative analysis, with the exception of the indicators of the benefits of the physics laboratory, which received favorable responses (Saputra et al., 2020). To the advantage of students, these authors suggested that physics teacher educators to enhance the physics laboratory design. It follows that, in addition to the modes of experimentation, the kind of instructional strategy also plays a crucial role in the success of physics laboratory experiments.

Another study comparing virtual and real experiments showed no statistically significant differences in students' attitudes of the relevance of laboratories in improving their learning (Kapici et al., 2020; Pyatt & Sims, 2012). That is, despite a general tendency to use computers in their learning, participants considered both real and virtual experiments to have the same impact on their learning as long as they were inquiry-based laboratories. For instance, Pyatt & Sims (2012) investigated the attitudes toward virtual and real experiments in first-year chemistry students. The findings showed that students preferred inquiry-based laboratories, whether they were real or virtual, and showed favorable attitudes toward both real and virtual experiments. Also, students felt that virtual laboratories were more open-ended and had better equipment usability. But, the study employed a crossover design and included software that was often utilized at the high school and college levels. Also, the participants had experience with inquiry-based science laboratories.

In a study to compare the effectiveness of a real versus a virtual laboratory in teaching simple circuits, it was found that there was no significant difference in students' attitudes toward these circuits (Tekbıyık & Ercan, 2015). According to the authors, there were no variations in students' attitudes toward basic electric circuits as a result of the introduction of virtual laboratories. The study, however, used different methods for the treatment and comparison groups. Participants in the treatment group were given unlimited opportunities for active participation in circuit elements, but in the comparison group, touching and seeing was the method used. Therefore, it is challenging to conclude that the results have been achieved by the type of experimentation that was conducted.

On the other hand, other scholars contend that physicality is important even when constructivist learning theories do not support it (Zacharia, 2007). Apart from that, virtual laboratories are a good substitute, in the opinion of many authors, for a number of reasons. Virtual laboratory experiments, for instance, might be an effective substitute in high-poverty and rural schools that lack the personnel and funding to run real laboratory experiments (Watson, 2007). These studies demonstrate that virtual laboratories have impacts that are comparable to those of real laboratories in terms of student attitudes. The ability to explore and manipulate experimental variables may be more important to students than the physicality of the equipment in today's learning environments (Zacharia, 2007). To fully understand the many laboratory delivery techniques, more research is required in a number of different directions due to the peculiarities and inconsistent results resulting from a variety of aspects, including design, context, learning outcomes, data gathering tools, and others.

According to observations made during laboratory sessions, the comparison group outperformed the blended experiment group in terms of circuit construction. The virtual experiment group received the lowest score from this two-phase observation of a laboratory session. Based on the results, real experiments could improve laboratory equipment and material identification as well as circuit construction better than blended or virtual experiments. The findings of the current study are in agreement with several earlier investigations. For instance, Marshal and Young (2006) concluded that simulation environments may not always live up to the expectation that they will allow users to change parameters, acquire measurements, and display data much more easily, rapidly, and consistently than they could in real experiments. The authors further stated that students might need more time to work in the virtual environment than in the real one. Moreover, Winn et al. (2006) found that individuals with past experience do the best in simulations.

The result of the study is also in accordance with previous studies in which innovative instructional strategies were employed (Díez-Palomar et al., 2020). The authors reported that students who participated in interactive and dialogic literary gathering showed positive attitudes towards learning. It can be implied that when innovative instructional approaches are applied, students develop more positive attitudes toward science learning. The authors also pointed out that these initiatives can improve students' attitudes about learning, particularly in laboratory settings. Hence, in addition to the experimentation approach used, the guided inquiry based approach may have helped students develop a favorable attitude toward the physics laboratory.

In terms of the blended mode of experimentation, its success depends on a variety of factors, including the participants' ability to shift between real and virtual experiments, their skills and knowledge needed for both real and virtual use, the availability of time, and the teacher's influence (Wörner et al., 2022). Indeed, the majority of PSPTs in the blended group of the current study noted that their ability to use the software and handle equipment was limited; the time allotted for completing the experiment activities was insufficient; and they were overburdened with pre-laboratory and post-laboratory questionnaires. On the other hand, while many of the results of studies supported by computer simulations are positive, a short-term understanding gain could not always transfer into long-term learning that is meaningful (Rutten et al., 2012). Most students would likely find it incredibly challenging to finish both experiments at once, so teachers must choose which experiment their students should begin with (Wörner et al., 2022). These concerns might affect how well they develop their practical skills. Last but not least, in light of this, the proverb "One Size Does Not Fit All" comes to mind.

Above all, the current study attempts to examine the efficacy of the type of manipulative on an intrinsic level. Previous studies, on the other hand, put a lot of attention on the treatment groups by giving them more time on task, resources, and instructional strategies, leaving the comparison untouched. In a meta-analysis study regarding blended learning, for instance, the US Department of Education noted that the benefits of blended learning should not be solely attributed to the media (Means et al., 2009). The authors pointed out that the disparities were thought to be due to differences in content, methodology, and learning time.

In conclusion, while virtual and blended experiments have advantages over real experiments stated in the literature, these advantages may not always hold true. For instance, some advantages of virtual experiments, such as the ability to change parameters, gather measurements, and display data more accurately and quickly than real experiments, might not be applicable in all circumstances (Marshall & Young, 2006). Problems that were frequently identified as hindering learning were inadequate prior knowledge and poor computer device handling skills of participants, the inconsistent nature of the test instruments, the wide variety of prior understanding of the topic among the students, and the small number of participants (Wörner et al., 2022). Similar results were found in the current study, when PSPTs frequently mentioned that they needed additional time, software, and computer training. Although it is often argued that technology is the new age, it is important to recognize this and make sure that students use computers appropriately in all circumstances. It is therefore expected that students in the treatment groups need more time, more effective teaching and learning techniques, and better instructional materials.

This method has sparked additional discussion, with some arguing that the positive outcome is due to both the type of manipulation as well as the additional assistance provided to the treatment groups (Hinkhouse, 2013; Means et al., 2009; Marshall & Young, 2006). Because of this, some authors asserted a strong association between blended learning outcomes and novel aspects such as comparative advantage, compatibility, usability, and department and faculty engagement (Raman et al., 2014). Nonetheless, improving student achievement across the board should be the major objective. Hence, whenever an intervention is done, a sufficient report on how the result was achieved should be made. If not, the findings are likely to be discussed over dinner rather than being used in the classroom.

Depending on the various combinations of laboratory parameters, the learning results for students should change (Basey et al., 2008). The type of implementation method may have an impact in addition to the type of manipulation (Wörner et al., 2022). As stated by the authors, the learner characteristics, components of the learning content, and supervision quality are only a few examples of potential confounders that frequently affect the outcomes of research finding. Other difficulties that were commonly cited as impeding learning included insufficient prior knowledge, poor digital device usage abilities, and a wide variety of prior knowledge in the subject among students.

Students would benefit if they were actively participating in the task. Poor instruction can cause even a well-designed blended approach to fall short (Basey et al., 2008). Because the instructional value of a simulation depends on how it is implemented, authors have emphasized that even a superior simulation can be useless if used improperly (Farrokhnia & Esmailpour, 2010; Wieman et al., 2008). Fundamental challenges that need to be addressed include educational efficacy and potential strategies to maximize learning using simulations. The idea that other factors, such as the instructional technique, instructional materials, and the time provided, also determine how effectively each mode of experimentation behaves was substantiated by a large number of earlier investigations. As a result, selecting appropriate laboratory learning environments requires careful consideration before initiating a large-scale implementation. Although the type of manipulative is significant, there are other elements that may influence how well the different learning environments function.

The results of the current study contrasted with those of the earlier studies, which may have been brought on by variations in the instructional strategies, instructional materials, time provided for tasks during interventions, student characteristics, context, and other aspects. It is helpful to know that blended and virtual physics laboratory experiments can serve as an alternative to or supplement to the conventional type of real experiments since the laboratory experiments and activities students engage in during physics class are essential to their understanding of the concepts covered in the course. The study offers insights into the fact that, in order to take advantage of the benefits of blended laboratory experimentation, many crucial factors must be taken into account in addition to the mode of physics laboratory experimentation.

5.2. Summary of the findings

In the current study, there was a significant difference in their mean posttest conceptual understanding scores between participants taught with blended and virtual laboratory experimentation, as well as between virtual and real laboratory experimentation. However, there was no significant mean difference in conceptual understanding between PSPTs taught using blended and real laboratory experimentation. Besides, participants in the treatment groups achieved significantly higher means as measured after the intervention, even though normalized gains were generally at a lower level. Pre-service physics teachers, physics teacher educators, and laboratory technicians all agreed that the interventions greatly helped their learning. They recommended extensive computer and PhET simulation training. It was also noticed that there was overload during the intervention as a result of compensating for educational schedules lost due to the COVID-19 pandemic.

It can be said that the virtual experiment group produced the highest effect on improving students' understanding of concepts related to electricity and magnetism. That is, virtual laboratory experiments helped teacher education college students’ enhance their conceptual understanding better than blended or real experiments. The challenge of using virtual and real experiments for the same laboratory experiment seemed challenging for participants in the blended experiment to manage. Using both virtual and real manipulatives during the specified period, they might have become fatigued from the same exercise. Participants in the blended experimental group also provided an explanation for this in terms of time constraints and workload.

To sum up, the current study found that virtual laboratory experiments in physics made the biggest difference in how well students understood the concepts of electricity and magnetism when compared to blended and real experiments. The challenge imposed on the participants in the blended experiment group while using virtual and real experiments for an activity appeared to be challenging for them to manage. The time constraints, lack of computer skills, familiarity with the simulations, and familiarity with the instructional strategies are some explanations for why the blended mode of experimentation may have made learning more challenging for participants.

Otherwise, if properly implemented, laboratory experiments in blended and virtual modes are effective ways to understand a wide range of physics concepts, particularly those relating to electricity and magnetism. Otherwise, if properly implemented, the blended and virtual modes of laboratory experiments are efficient ways to understand a wide range of physics concepts, particularly the topics of electricity and magnetism.

Pre-service physics teachers who received instruction using all three types of laboratory experiments did not demonstrate any appreciable change in their conceptions of aspects of the nature of science when understanding of the nature of science was compared before and after the intervention. To put it another way, there was no significant difference in mean between PSPTs who were taught the Experimental Physics II laboratory course through blended, virtual, or real laboratory experiments on the posttest outcomes. The understanding of the nature of science was not significantly influenced by any of the three laboratory learning environments.

This means that the use of blended, virtual, and real forms of experimentation with guided inquiry-based learning had no impact on the participant's understanding of NOS. The modes of physics experimentation carried out over the course of a semester in a physics laboratory course had no effect on the NOS ideas. This has been shown by quantitative and qualitative assessments of the views of the NOS components. During the process, it was noticed that the treatment groups had more PSPTs actively engaged in the laboratory sessions and interacting with the teacher, the laboratory technician, and their peers than the comparison groups did. It has been demonstrated that integrated laboratory experimentation in physics is effective for a number of physics learning goals, but it was unable to change pre-service physics teachers' views on NOS. It can be inferred that using different instructional strategies should be aligned with the learning outcomes that students need to achieve.

In terms of attitude toward physics laboratories, the results of the study indicated that all three modes of physics laboratory experiments elicited favorable attitudes toward physics laboratories. Furthermore, there was a statistically significant difference between the groups, with the blended mode of physics laboratory being the most effective. Based on the findings of the current study, blended laboratory experiments improved attitudes towards laboratories more than virtual and real laboratory experiments. After implementing the intervention, there was a favorable attitude in each of the three study groups. In addition, the treatment group participants said they preferred learning through blended and virtual experiments.

The three participant groups in the study all had favorable attitudes towards the three modes of laboratory experimentation. Besides, the attitudes of PSPTs toward the physics laboratory significantly changed when they were taught using a blend of experimentation rather than only virtual and real experimentation. Together with previous studies, it is possible to conclude that combining virtual and real laboratory experiments resulted in favorable attitudinal changes in pre-service physics teachers. It may also be concluded that teacher education institutions can provide blended physics laboratory education with an inquiry-based learning strategy to enhance pre-service physics teachers' attitudes. These teachers are required to lay the foundation for children to pursue careers in science.

The qualitative data revealed that all the participants in the treatment and comparison groups noticed differences between the previous and the newly implemented mode of experimentation and, they preferred the mode of experimentation employed. The participants in the BEG replied that they preferred the intervention as it helps to visualize abstract concepts and offer practical experience. But, raised concerns with regard to time constraint, task overload, access to computers, technology skills, etc. The participants in the VEG replied favorably about visualization, interaction, interactive, and safety benefits of PhET simulations. But, raised concerns about lack of hands-on experience, fear of teaching in schools, shortage of computers, and skills on PhET simulations. The participants in the REG replied favorably with regard to the facilitation and pre-post lab questions. In terms of material identification and constructing circuits, PSPTs in REG were better followed by BEG.

Physics teachers and laboratory technicians raised concerns such as inadequate skill of computers, challenge to be acquainted with many tasks, time constraint, workload, and considering simulations as fun by some students. The time-on-task constraints, an inadequate level of skill in switching from one form of investigation to another, and a lack of proficiency with computers and PhET may be the possible reasons for those in BEG.

In sum, the results of the current study showed that PhET simulations are generally useful teaching tools. The challenge is in how well teachers and students implement the PhET-recommended strategies. For different modes of laboratory experimentation to be successful, it is necessary to investigate the implementation of these PhET-recommended strategies and their effects on the physics learning of students.

5.3. Conclusions

- The blended mode of laboratory experimentation was effective in enhancing students' attitudes toward physics laboratories, while the virtual mode was beneficial in developing conceptual understanding of electricity and magnetism concepts.

- On the other hand, the blended, virtual, and real modes of experimentation had no impact on the students' conceptions of the studied aspects of the nature of science. That is to say, it was found that none of the modes of experimentation were successful in advancing understanding of the NOS concepts.

- The majority of participants favored blended and virtual modes of experimentation over real ones, despite some participants questioned about access to computers, additional software training, and more practice time.

- If challenges associated with the nature of the interventions are resolved, the interventions might have a positive impact on student learning in many different ways.

5.4. Recommendations and Implications of the study

It is no longer debatable that physics laboratory experimentation is an essential component of quality physics learning. What is debatable is how well the laboratory learning environment is designed for effective physics learning. The advancement of ICT has favored technology-enhanced learning in the education system, which has shed light on science laboratories in general and physics laboratories in particular. Blended and virtual physics laboratory experiments have the potential to improve physics learning if properly implemented, as evidenced by conceptual understanding and attitude toward physics laboratories. Though it is not stated explicitly, there is evidence that laboratory experiments can improve understanding of the nature of science. Thus, the decline in physics achievement and interest at CTEs can be addressed through informed optimal design of the physics laboratory, such as through the use of interactive virtual simulations in addition to the real laboratory.

The following recommendations were made for practical, methodological, and theoretical reasons in light of the findings and conclusions of the current study.

- The results of this study offer evidence in support of earlier reports in the literature about the efficiency of blended and virtual modes of physics experimentation in laboratories. The global context necessitates the use of alternative physics laboratories. It has been shown that employing appropriate environments and instructional strategies can result in improved student learning of physics. Technology-enhanced laboratories, particularly blended ones, could foster learning such as conceptual understanding and attitudes toward laboratories if access to computers, computer training, and PhET interactive simulations is fulfilled. Furthermore, the physics laboratory at CTEs should explicitly include understanding of the nature of science as a goal in order to improve conceptions of the various aspects of NOS. Concerns raised by participants and implementers, such as a lack of computers, time constraint in the laboratory session, and the provision of training on PhET simulations, should be addressed for improved physics learning.

- The utilization of ICT-supported labs, like PhET simulations, should be encouraged by MOE organizational sections like the Physics Education Technique Improving Center Directorate. It is also essential to provide ICT infrastructure and capacity building.
- Curriculum designers should consider the various laboratory learning environments in physics education, such as blended and virtual modes. Furthermore, teacher educators must be knowledgeable about how to integrate technology-enhanced laboratories into their physics classrooms.
- To foster a positive attitude in pre-service physics teachers toward the physics laboratory and, subsequently, the subject of discussion, different ICT-supported modes of experimentation should be used. One of these alternatives is the blended mode of experimentation, which is intended to encourage pre-service physics teachers to have a positive attitude about the physics laboratory.
- Since preservice physics teachers have the responsibility to lay a foundation for children in the future, they have to be engaged in physics experiments and enhance their abilities through alternative modes of experimentation in CTEs. Additionally, in order to keep up with the most recent developments in teaching physics, physics teacher educators should take part in several refresher trainings. This includes teaching students how to use various manipulatives to learn physics through laboratory experiments.
- Anyone who intends to carry out a blended laboratory study should make sure that the participants are given the necessary instruction regarding instructional materials and methods. Furthermore, attention should be given to the way the laboratory setting for learning will be supported as well as the types of manipulatives that will be employed.

- Even though physics laboratory experimentation in different modes did not enhance NOS views, it is crucial to explicitly incorporate NOS elements and integrate these while developing laboratory materials. In the end, it is essential to clearly define the changes in question that the students will be achieving before choosing and implementing different modes of laboratory experiments into practice. Although there was no significant alteration in understanding of NOS after the intervention in this study, emphasis should be placed on NOS aspects in teacher education colleges because understanding the nature of science is essential for school teachers. To determine the status of science teachers in the area, a large-scale survey of understanding of the nature of science must be conducted in the future. This method will assist in the development of appropriate interventions for pre-service physics teachers. Along with previous research, college teacher educators should emphasize NOS aspects when teaching theoretical physics courses, experimental laboratory courses, and physics teaching methods. Another potential future research area related to the issues could be the perspectives of physics teacher educators on the nature of science. This should be done using an open-ended interview and a written data collection instrument to gain an in-depth understanding of the nature of science by physics teacher educators.
- More study on various learning outcomes, settings, and methodologies is required to fully use ICT's benefits in our laboratories as well as throughout the educational system because the results on the efficacy of technology-enhanced learning in general are inconsistent.
- Despite challenges, the blended and virtual experiments have been shown to be somewhat successful, and as a result, an appropriate level of preparation is required to enhance physics learning and to benefit from technology-assisted learning.

In sum, the MOE should promote the use of ICT-supported physics laboratories, such as PhET simulations, provide ICT infrastructure and capacity building. The physics curriculum developers should promote the use of PhET simulations, indicate facilitation strategies, and include NOS aspects explicitly with appropriate strategies in laboratory course for PSPTs. CTEs should encourage the use of ICT-enhanced laboratories and provide up-to-date training for teachers and physics laboratory technicians. CTE physics teachers should use PhET simulations to physics lesson and review best practices to optimize learning.

5.5. Limitation of the study

Because of methodological concerns, the current study is not without limitations. The resulting groups are likely to differ in various respects when participants are not randomly assigned to conditions. With non-interacting groups of pre-service physics teachers from three CTEs, efforts have been made to make the groups as comparable as possible in order to ensure the study's internal validity. For instance, the participants shared comparable attributes in terms of their ages, educational backgrounds, prior teaching and learning experience, some teacher characteristics, and CTE contexts. Because PSPTs were not assigned at random, it is challenging to eliminate out the problem of confounding variables that the researcher was unable to regulate. This may increase the probability that there are additional variations between the participants of each group. In fact, efforts were made to reduce confounding variables such as instructional material, teacher and laboratory technician experiences, laboratory facilities, and instructional strategy. However, since the students were not truly assigned at random to the conditions, it is still possible that other significant confounding factors existed that the researcher was unable to regulate.

Furthermore, the study was conducted just after educational institutions reopened following a lockdown due to the COVID-19 pandemic. The academic calendar was too tight, and all of the study participants were busy. This may have imposed a burden on the study participants, affecting their learning in the laboratory. The researcher encouraged the students and teacher to finish on time. Furthermore, the students were challenged on their ability to use the computer and the PhET interactive simulations. They were also unfamiliar with the facilitation technique, which took some time to adapt to. However, an attempt was made to take action when necessary, and the researcher attempted to complete the study as planned.

Intervention and data collection were held for one academic semester. It would have been good if surplus data were collected for more than one semester to get additional data for further clarification of results. This study was based on only limited outcome variables (conceptual understanding, understanding of the nature of science, and attitude towards physics laboratory), which might be susceptible to generalization as there are many outcome variables of physics learning. Additionally, the small sample sizes in each study group and the limited number of research sites could have an impact on the study's findings. For each study group, intact classes were taken, and the limited sample size may indicate that there is still a problem with physics enrolment in CTEs.

There might also be other limitations that were not apparent but influenced the results of the current study. As a result, the researcher would like to kindly express that the conclusions drawn and recommendations forwarded following the findings of the research might have been influenced by the limitations pointed out above.

5.6. The way forward for future project in the field

Technology-enhanced physics laboratories are a growing concern in Ethiopia's educational system. Much work has been done and research has been conducted in developed countries to determine how a student can best learn from a physics laboratory using interactive virtual simulations. The interest and experience of teacher educators, students' interest and prior knowledge, the availability of infrastructure such as computers and the internet, administrative issues, work overload, students' and teachers' philosophy and/or perspectives on technology-enhanced learning, and other factors can all influence the effectiveness of various modes of laboratory experimentation. A thorough review of the literature should be conducted, as well as a large-scale study, so that lessons can be learned before making large-scale investments in the area.

As a result, the researcher invites interested scholars to collaborate in establishing a project with other institutions working in the field, such as PhET-Global and the PhET Educator Community for Africa, to improve the quality of physics education. This is because establishing a project is more beneficial than relying just on the findings of a single investigation or article. By doing this, a comprehensive understanding of blended physics laboratory experiments for PSPTs could be obtained, and a strategy for redesigning physics laboratory courses based on a blended approach could be carried out.

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LIST of PUBLICATIONS

Three articles have been published in reputable international publications that have accreditation. The publications used original data from the dissertation. The abstracts, citations, and links for each article are given below:

1. Mihret, Z., Alemu, M., & Assefa, S. (2022). Effects of Blending Virtual and Real Laboratory Experimentation on Pre-Service Physics Teachers' Attitudes Toward Physics Electricity and Magnetism Laboratories. *Science Education International*, *33*(3), 313-322. https://doi.org/10.33828/sei.v33.i3.7

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ORIGINAL ARTICLE

Effects of Blending Virtual and Real Laboratory Experimentation on Pre-Service Physics Teachers' Attitudes Toward Physics Electricity and Magnetism Laboratories

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ABSTRACT

This study examined the effect of blended laboratory experiments on pre-service physics teachers' (PSPTs') attitudes toward physics laboratories. The research design was a quasi-experimental pre-test and post-test comparing groups. Participants were 63 2nd-year PSPTs' enrolled in a physics diploma program from three colleges of teacher education. The treatment groups performed blended and virtual laboratory experiments, whereas the comparison group conducted real laboratory experiments. Data were collected before and after intervention using a 34-item adapted attitude toward physics laboratory questionnaire with a Cronbach alpha value of 0.765. Data were analyzed using descriptive statistics, paired-sample t-test, one-way ANOVA, and Tukey *post hoc* comparisons. The findings revealed a statistically significant difference in mean post-test results between the treatment and comparison group. The Tukey HSD *post hoc* analysis revealed that the difference in mean between blended and real was statistically significant, but not on other combinations. Descriptive statistics showed slight attitudinal improvement from pre-test to post-test. This improvement was statistically significant for blended and virtual groups but not in real groups. Blending physics laboratory experiments can be used to enhance attitudes toward physics laboratories. Based on the conclusions, recommendations are made.

KEY WORDS: Attitude; blended learning; laboratory; pre-service teachers; physics

2. Mihret, Z., Alemu, M., & Assefa, S. (2023). Effectiveness of blended physics laboratory experimentation on pre-service physics teachers' understanding of the nature of science. *Pedagogical Research*, 8(1), em0144. https://doi.org/10.29333/pr/12607

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Effectiveness of blended physics laboratory experimentation on pre-service physics teachers' understanding of the nature of science

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ABSTRACT

The objective of this study was to examine the effectiveness of blended physics laboratory experimentation on pre-service physics teachers' (PSPTs') understanding of the nature of science (NOS) during an electricity and magnetism laboratory course. The study used a non-equivalent comparison group using a pre-test-post-test quasi-experimental design that contrasted blended, virtual, and real mode of physics experimentations. A total of 63 PSPTs, 16 in blended experimental group, 26 in virtual experimental group, and 21 in real experimental group, participated in the study. Except for the type of manipulatives, the experiments in all the three cases were the same. Quantitative Likert-type questions were administered before and after the intervention and open-ended questions were administered after the intervention. The quantitative data were analyzed using one-way ANOVA and ANCOVA, while the qualitative data were categorized under naïve, mixed, and informed views. The results revealed that experimenting with blended, virtual, and real manipulatives were found to be ineffective in enhancing understanding of NOS on the PSPTs'. Apart from the type of experiment used, it was suggested that adequate consideration be paid to NOS issues in the laboratory courses in order to obtain well-educated and trained physics teachers.

Keywords: blended physics laboratory experimentation, guided inquiry-based approach, pre-service physics teachers, understanding of nature of science

3. Mihret, Z., Alemu, M., & Assefa, S. (2023). Assessment of pre-service physics teachers' conceptual understanding in electricity and magnetism. *Momentum: Physics Education Journal*, *7*(1), 33–47. https://doi.org/10.21067/mpej.v7i1.7990

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Assessment of pre-service physics teachers' conceptual understanding in electricity and magnetism

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Abstract: This study focused on an assessment of pre-service physics teachers' conceptual understanding of physics in the domain of electricity and magnetism concepts. The study employed a descriptive survey method of research. The study sample consisted of 100 pre-service physics teachers from five teacher education colleges during the academic year 2021/21. The study used preliminary data from a PhD dissertation that was gathered by administering a conceptual understanding test on electricity and magnetism, which contained 32 items adapted from standardized tests. The data were analyzed using descriptive statistics, one sample t-tests, independent samples t-tests, and one-way ANOVA. The results of the one sample t-test showed that the conceptual understanding test scores for electricity and magnetism were considerably below 50 and 70 which are the national standard pass mark points and the baseline for certification of competency to the teaching profession, respectively. ANOVA analysis revealed that there was a statistically significant mean difference among the pre-service physics teachers in the colleges. The post hoc test analysis showed that there was a statistically significant mean difference between pre-service teachers from two colleges. The independent samples t-test revealed that there was statistically significant mean difference between test scores of males and females in favor of male pre-service physics teachers. In addition, the participation of female candidates was too low compared to their male counterparts. In conclusion, the achievement of pre-service physics teachers was below the expected values; differences among colleges were detected; and there was an achievement and participation imbalance in relation to gender, though consecutive measures were taken. Based on the conclusions, recommendations are given that could be applicable.

Keywords: conceptual understanding; electricity and magnetism; Pre-service physics teacher

APPENDICES

Appendix A: Electricity and Magnetism Conceptual Understanding Test

Addis Ababa University

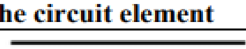
College of Education and Behavioral Studies

Department of Science and Mathematics Education

Dear Pre-service Physics Teachers, the purpose of this test is to investigate the effectiveness of different modes of physics experimentation. You are highly appreciated to participate in this test. The researcher assures you that any information about the participants will be handled with care and confidentiality. Moreover, the scores are used only for the research purpose. Thank you in advance for your willingness to take part in this test, your time, and your responsibility.

The tests are prepared from Experimental Physics II (Phys 211) laboratory course. Before you answer the questions, try to understand the questions well and write your answer in the space provided. The time allowed to complete all the questions is approximately one hour and if you finish early please check your work before handling.

In this test, the battery is to be assumed ideal, that is to say, the internal resistance of the battery is negligible unless you are told otherwise. In addition, assume the wires have negligible resistance. The circuit symbols shown below are key and essential in this test and please carefully study before you begin the test.

Name of the circuit element	**Circuit Symbol**
	Connecting wire or cable
	Cell/DC Voltage Source
	Battery/DC voltage source
	Light bulb
	Resistor
	Ammeter
	Voltmeter
	Open Switch
	Closed Switch

PART I: Please fill your background information

1. Name ________________________________ Id No _________ Roll Number ______

2. Name of the College: ______________________________

3. I am (tick only one) Female ☐ Male ☐

4. Age: ☐

5. Grade Completed: 10^{th} ☐ 12^{th} ☐ TVET ☐ Other__________

6. How would you rate your level of computer expertise?

Never used a computer ☐ Beginner in using computer ☐

Good in using computer ☐ Very good in using computer ☐

Excellent in using computer ☐

PART II: Read the questions carefully and circle the letter that contains the best answer from the given alternatives.

1. Two electrically neutral objects are rubbed together. After this process is complete the net charge on one of the objects is +Q. The net charge on the other object is _________________.
A) 0 B) +Q/2 C) –Q/2 D) +Q E) –Q

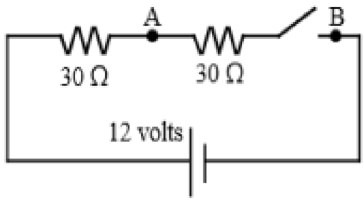
2. A small positive charge, +q, is brought near but does not make contact with a small metal sphere, as shown in the diagram below. Initially the metal sphere is electrically neutral (no excess charge). Which statement is correct after the charging process?

A) The net charge on the metal sphere is –q.
B) The net charge on the metal sphere is +q.
C) The net charge on the metal sphere is 0.
D) The net charge on the metal sphere is +q/2.
E) The net charge on the metal sphere is –q/2.

3. Suppose a neutral metal sphere is touched by a negatively charged metal rod. What type of charge would the metal sphere acquire after the charging process?
A) Positive charge B) Negative charge C) Neutral D) Undetermined E) None

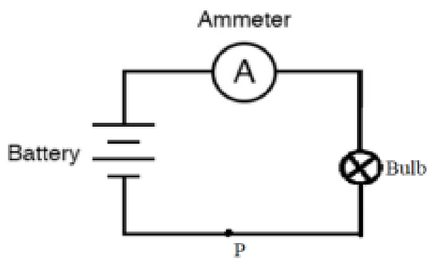
4) If you double the current through a battery, is the potential difference across a battery doubled?
A) Yes, because Ohm's law says $V = IR$.
B) Yes, because as you increase the resistance, you increase the potential difference.
C) No, because as you double the current, you reduce the potential difference by half.
D) No, because the potential difference is a property of the battery.
E) No, because the potential difference is a property of everything in the circuit.

5) What is the potential difference between points A and B in the circuit shown to the right, while the switch is open?
A) 0 V B) 3 V C) 6 V D) 12V E) None

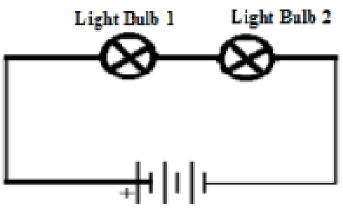


6. A certain electrical circuit contains a battery with three cells, wires and a light bulb. Which of the following would cause the light bulb to shine less brightly?
A) Adding another cell to the circuit
B) Decreasing the resistance
C) Decreasing the voltage of the battery
D) Open the switch of the circuit
E) None

7. Suppose the ammeter to the right is measuring a current of 2 Ampere. If the ammeter is moved to a different position of point P, what will be the new reading of the ammeter?
A) reads the same value
B) reads greater than 2 Ampere
C) reads less than 2 Ampere
D) difficult to determine
E) None



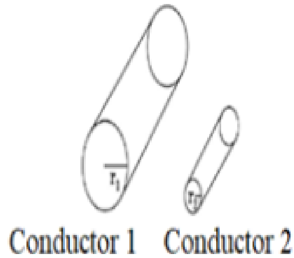
8. The resistance of bulb 1 is greater than the resistance of bulb 2 in the circuit shown to the right. How do you compare the potential difference across the light bulbs 1 and 2?



A) The potential difference across bulb 1 is greater than the potential difference across bulb 2.
B) The potential difference across bulb 1 is less than the potential difference across bulb 2.
C) The potential difference across bulb 1 is the same as the potential difference across bulb 2.
D) It is not possible to compare the potential difference across the bulbs.

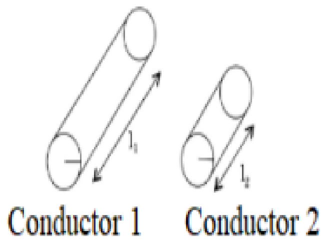
9. Compare the current through the light bulbs using the figure in question № 8 above.
A) The current through bulb 1 is greater than the current through bulb 2.
B) The current through bulb 1 is less than the current through bulb 2.
C) The current through bulb 1 is the same as the current through bulb 2.
D) It is not possible to compare the current through the bulbs.

10. The conductors shown in the diagram to the right are identical in every way except that the radius of conductor 1 is greater than the radius of conductor 2 (that is $r_1>r_2$). Compare the resistance of the two conductors.



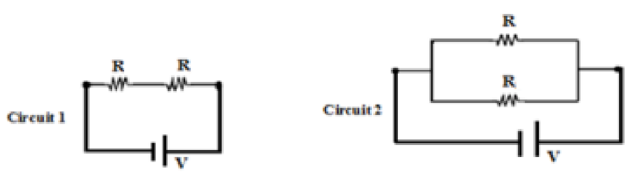
A) The resistance of conductor 1 is greater than the resistance of conductor 2.
B) The resistance of conductor 1 is less than the resistance of conductor 2.
C) The resistance of conductor 1 is equal to the resistance of conductor 2.
D) It is not possible to compare the resistance of the conductors.

11. The conductors shown in the diagram to the right are identical in every way except that the length of conductor 1 is greater than the length of conductor 2 ($l_1>l_2$). Compare the resistance of the two conductors.



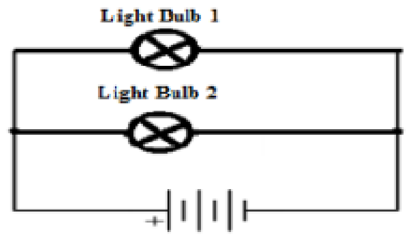
A) The resistance of conductor 1 is greater than the resistance of conductor 2.
B) The resistance of conductor 1 is less than the resistance of conductor 2.
C) The resistance of conductor 1 is equal to the resistance of conductor 2.
D) It is not possible to compare the resistance of the conductor.

12. In the circuit shown below, what is the resistance of circuit 1 in terms of circuit 2 when the resistors in the two circuits are identical?



A) Double B) Four times C) The same as D) Half E) One quarter (1/4)

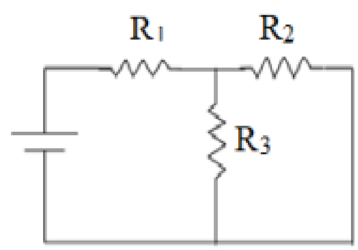
13. In the circuit shown to the right, the resistance of bulb 1 is greater than the resistance of bulb 2. How do you compare the potential difference across the light bulbs 1 and 2?



A) The potential difference across bulb 1 is greater than the potential difference across bulb 2.
B) The potential difference across bulb 1 is less than the potential difference across bulb 2.
C) The potential difference across bulb 1 is the same as potential difference across bulb 2.
D) It is not possible to compare the potential difference across the bulbs

14. Compare the current through the bulbs using the figure in question № 13 above.
A) The current through bulb 1 is greater than the current through bulb 2.
B) The current through bulb 1 is less than the current through bulb 2.
C) The current through bulb 1 is the same as the current through bulb 2.
D) It is not possible to compare the current through the bulbs.

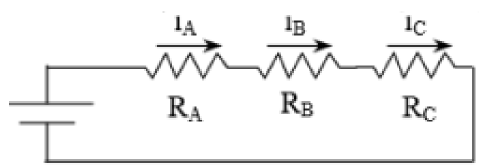
Questions 15 and 16 refer to the diagram shown to the right of a circuit with three resistors.



15. Which resistors in the diagram are in series?
A) R_1 and R_2 B) R_1 and R_3 C) R_2 and R_3 D) None

16. Which resistors in the diagram are in parallel?
A) R_1 and R_2 B) R_1 and R_3 C) R_2 and R_3 D) None

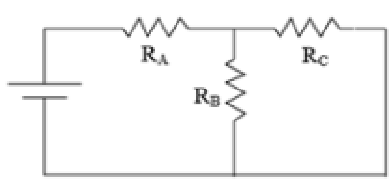
17. In the diagram to the right, suppose all three resistors are identical, $R_A=R_B=R_C$. What can you say about the current I_A through R_A?



A) $I_A=I_B$, only B) $I_A=I_C$, only C) $I_A=I_B-I_C$

D) $I_A=I_B+I_C$ E) $I_A=I_B=I_C$

Questions 18-19 refer to the circuit given below in which R_A, R_B, and R_C all have different values.



18. Which resistors in the diagram have the same magnitude of current running through them?

A) R_A and R_B B) R_A and R_C C) R_B and R_C D) All of them E) None of them

19. Which resistors in the diagram have the same potential difference across them?
A) R_A and R_B B) R_A and R_C C) R_B and R_C D) All of them E) None of them

20. What happens to the resistance of the light bulb when the switch is turned on?

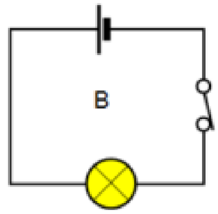
A) The resistance goes to infinity

B) The resistance increases

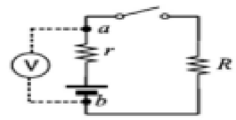
C) The resistance decreases

D) The resistance remains constant

E) The resistance goes to zero



21. A battery with an electromotive force of 12V and an internal resistance of 200 Ohm is placed in series with a 1000 Ohm resistor as shown in the figure. When the switch is open, the potential difference between points a and b of the battery will be

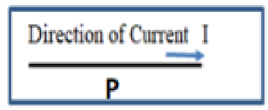


A) equal to 12V B) greater than 12V C) less than 12V D) 0V

22. When the switch is closed and there is a stationary current I, the potential difference between terminals a and b of the battery will be (Use the figure in question № 21 above)

A) equal to 12V B) greater than 12V C) less than 12V D) 0V

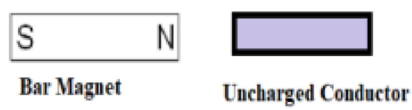
23. The net magnetic field at point P in the figure in the box to the right is pointing in the direction of



A) → C) Into the page (x)

B) ↑ D) Out of the page (.) E) There is no net magnetic field.

24. A bar magnet is held very close to an uncharged nonmagnetic conductor as shown in the figure below. Both the conductor and the magnet are at rest. In what direction does the conductor feel a magnetic force due to the magnet?

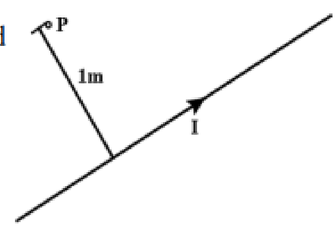


A. The nonmagnetic conductor does not feel a magnetic force

B. Into the page (x) C. Out of the page (.)

D. Toward the magnet (←) E. Away from the magnet (→)

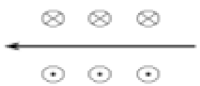
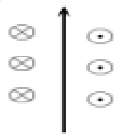
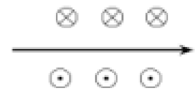
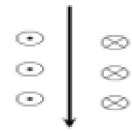
25. How will doubling the current through a wire affect the magnetic field due to the wire at a distance 1m directly above the wire?



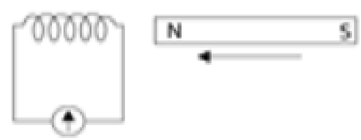
A) The direction of the magnetic field will curve sharper
B) The magnetic field strength will double
C) The direction of the magnetic field will reverse
D) The magnetic field strength will quadruple

26. Which one of the following is true about the strength of magnetic field around a current carrying conductor?
A) Inversely proportional to current but directly proportional to the square of distance from wire.
B) Directly proportional to the current but inversely proportional the square of distance from wire.
C) Directly proportional to the distance and inversely proportional to the current
D) Directly proportional to the current and inversely proportional to the distance from wire.

27. Which of the following diagrams represent the directions of the magnetic field around a current carrying conductor using the right hand rule?

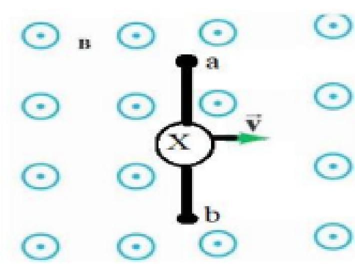
A) 
B) 
C) 
D) 

28. When a magnet was moved into the coil of wire shown in the diagram to the right, there was a small reading on the galvanometer. Which change would increase the size of the reading?



A) Moving the South Pole in
B) Pulling the magnet out
C) Pushing the magnet in faster
D) Unwinding some of the turns of wire

29. A 1m metal bar with a bulb at its center enters a region with a uniform stationary magnetic field as shown below with constant velocity of 15m/s.

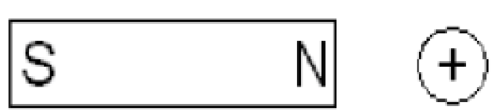


Which one of the following is **not** true?
A) The cause of electromotive force is motional.
B) There is no potential difference.
C) There is electromagnetic induction in the circuit.
D) The electromotive force generated sets up a potential difference due to charge separation between points a and b.

30. Which one of the following is true about induction from a magnet moving through a coil?
A) Voltage is observed when the magnet is at rest in or near the coil.
B) Voltage induced becomes smaller as the magnet approaches the center of the coil
C) Voltage sign rapidly changes sign as the magnet passes through the middle of the coil.
D) All of the above statements are

31. The magnitude of induced Electromotive force (EMF) depends on
A) speed of motion of coil and magnet only
B) number of turns of coil only
C) current passing through coil
D) speed of motion of coil , magnet and number of turns of coil

32. A bar magnet is held very close to a positive point charge as shown in the figure below. Both the point charge and the magnet are at rest. In what direction does the point charge feel a magnetic force due to the magnet?



A) The point charge does not feel a magnetic force.
B) Into the page (x)
C) Out of the page (.)
D) Toward the magnet (←)
E) Away from the magnet (→)

Appendix B Views of nature of science questionnaire

English Version

Dear respondents of this questionnaire, scholars suggest that science teachers need to know and understand the nature of science. Therefore, this questionnaire is provided for a research purpose aiming at examining the knowledge and perspectives of pre-service physics teachers on science and the nature of science. The questions deal with scientific knowledge, the nature of science, and how scientists study science, and you may have different levels of agreement with the questions asked. Accordingly, in order to achieve the objectives of this study, the following statements are presented to pre-service physics teachers to be completed depending on their personal beliefs.

Part 1

By reading and understanding the statements number 1 through 14 carefully, circle the level that you believe is appropriate for each idea. Agreement decision levels represent: 1= strongly disagree, 2 =disagree, 3= disagree, 4= agree and 5= strongly agree. Thank you in advance for your cooperation.

No	Statement	Decision of Agreement/Level				
1	Science is an attempt to explain natural phenomena.	1	2	3	4	5
2	Scientific knowledge is durable, but tentative.	1	2	3	4	5
3	Scientific knowledge relies heavily on observation, experimental evidence, rational arguments and skepticism.	1	2	3	4	5
4	Scientific laws and theories have different roles in science.	1	2	3	4	5
5	New knowledge must be reported clearly and openly.	1	2	3	4	5
6	Scientists require accurate recordkeeping, peer review and replicability.	1	2	3	4	5
7	Observations are theory-laden.	1	2	3	4	5
8	There is no one way to do science.	1	2	3	4	5
9	People from all cultures contribute to science.	1	2	3	4	5
10	Scientists are creative.	1	2	3	4	5
11	The history of science reveals both an evolutionary and a revolutionary character.	1	2	3	4	5
12	Science is part of social and cultural traditions.	1	2	3	4	5
13	Science and technology impact on each other.	1	2	3	4	5
14	Scientific ideas are affected by the social and historical milieu.	1	2	3	4	5

Part 2: For the questions below, please explain your answer briefly with examples.

1. With examples, explain why you think scientists' observations and interpretations are the same OR different.

2. With examples, explain why you think scientific theories do not change OR how (in what way) scientific theories change.

3. With examples, explain the nature of and difference between scientific theories and scientific laws.

4. With examples, explain how society and culture affect OR do not affect scientific research.

5. With examples, explain how and when scientists use imagination and creativity OR do not use imagination and creativity.

6. With examples, explain whether scientists follow a single, universal scientific method OR use different types of methods.

Amharic Version

ውድ የዚህ መጠይቅ መልስ ሰጪዎች፣ የሳይንስ መምህር አስተማሪዎች የሳይንስን ምንነት ማወቅ እና መገንዘብ እንዳለባቸው ምሁራን ጠቁመዋል ። አንተ/አንቺ ደግሞ ዕጩ የፊዚክስ ሠልጣኝ መምህር/ት ነህ/ሽ ። የዚህ መጠይቅ ዋና ዓላማ ደግሞ የፊዚክስ ዕጩ መምህራን ስለ ሳይንስ እና የሳይንስ ተፈጥሮ ያላቸውን አመለካከት ለመመርመር የተዘጋጀ ነው። በዚህ መጠይቅ ሁለት አይነት ጥያቄዎች ቀርበዋል።

በክፍል አንድ የቀረቡት ጥያቄዎች/መግለጫዎች የሳይንስ ዕውቀት ፣ የሳይንስ ተፈጥሮ እና የሳይንስ ሊቃውንት ሳይንስን እንዴት እንደሚያጠኑ የሚመለከቱ ሲሆን በቀረቡት ጥያቄዎች የተለያየ የስምምነት ደረጃ ሊኖርህ/ሽ ይችላል። በዚህም መሰረት የዚህ ጥናት ዓላማ ከግብ ለማድረስ ይረዳ ዘንድ ሠልጣኝ መምህራን እንደየግል እምነታቸው ሃሳባቸውን ከ 1 እስከ 5 ድረስ ደረጃ የሚሰጡባቸው ሃሳቦች ቀርበዋል። ከ 1 እስከ 14 የቀረቡትን መግለጫዎች በሚገባ በማንበብ እና በመረዳት ለእያንዳንዱ ሃሳብ ይመጥናል ብላችሁ የምታምኑበትን ደረጃ የያዘውን ቁጥር በማክበብ አሳዩ። የስምምነት ውሳኔ ደረጃዎችም **1 = በጣም አልስማማም፣ 2 = አልስማማም፣ 3 = መወሰን አልቻልኩም፣ 4 = እስማማለሁ እና 5 = በጣም እስማማለሁ** የሚለውን ይወክላሉ።

በክፍል ሁለት ደግሞ በምሳሌ ሊብራሩ የሚገባቸው ክፍት ጥያቄዎች ስለቀረቡ ለጥያቄዎቹ መልስ ይሆናል የምትሉትን በተሰጠው ቦታ በግልፅ እና በምሳሌ አብራሩ። ስለ ትብብርህ/ሽ በቅድሚያ አመሰግናለሁ። መልካም የትምህርት ዘመን ይሁንላችሁ!!!

ክፍል አንድ፡ በደረጃ የቀረቡ ጥያቄዎች

ተ.ቁ	መግለጫ	የስምምነት ውሳኔ ደረጃ				
1	ሳይንስ የተፈጥሮ ክስተቶችን ለማስረዳት/ለመግለፅ የሚደረግ ሙከራ ነው ።	1	2	3	4	5
2	ሳይንሳዊ ዕውቀት ዘላቂ ቢሆንም ሊቀየር የሚችል ነው ።	1	2	3	4	5
3	ሳይንሳዊ ዕውቀት በምልከታ ፣ በሙከራ ማስረጃ ፣ በምክንያታዊ ክርክሮች እና በጥርጣሬ ላይ በእጅጉ ይተማመናል ።	1	2	3	4	5
4	ሳይንሳዊ ሕጎች እና ንድፈ ሐሳቦች በሳይንስ ውስጥ የተለያየ ሚና አላቸው ።	1	2	3	4	5
5	አዲስ እውቀት በግልፅ እና በሐቀኝነት ሪፖርት መደረግ አለበት ።	1	2	3	4	5
6	የሳይንስ ሊቃውንት ትክክለኛ ምዝገባን ፣ የአቻዎችን ግምገማ እና አስተማማኝነትን ይጠይቃሉ ።	1	2	3	4	5
7	ምልከታዎች በንድፈ ሀሳብ የተጫኑ/የሚመሩ ናቸው ።	1	2	3	4	5
8	ሳይንስን ለመስራት አንድ ወጥ የሆነ መንገድ የለም ።	1	2	3	4	5
9	በሁሉም ባህሎች ያሉ ሰዎች ለሳይንስ አስተዋፅዖ ያደርጋሉ ።	1	2	3	4	5
10	የሳይንስ ሊቃውንት በፈጠራ የተካኑ ናቸው ።	1	2	3	4	5
11	የሳይንስ ታሪክ የዝግመተ ለውጥ እና የአብዮታዊ ባህሪን ያሳያል ።	1	2	3	4	5
12	ሳይንስ የማህበራዊና ባህላዊ ሁነቶች አካል ነው ።	1	2	3	4	5
13	ሳይንስ እና ቴክኖሎጂ አንዱ በሌላው ላይ ተጽዕኖ ያሳድራሉ	1	2	3	4	5
14	ሳይንሳዊ ሀሳቦች በማኅበራዊ እና ታሪካዊ ሁኔታዎች ችግር ይገጥማቸዋል ።	1	2	3	4	5

ክፍል ሁለት፡ ለጥያቄዎቹ እባክዎን መልስዎን በአጭሩ እና በምሳሌ ያስረዱ ።

1. የሳይንስ ሊቃውንት በሚያደርጓቸው ምልከታዎች እና በሚሰጧቸው ትርጓሜዎች ተመሳሳይ ናቸው ወይስ ይለያያሉ ብላችሁ ታስባላችሁ? ምክንያታችሁን በምሳሌዎች አብራሩ።

2. ሳይንሳዊ ንድፈ ሐሳቦች ሊለወጡ ወይም ሊቀየሩ ይችላሉ ወይስ ቋሚ ናቸው ብላችሁ ታስባላችሁ?ምክንያታችሁን በምሳሌዎች አብራሩ።

3. በሳይንሳዊ ንድፈ ሃሳቦች እና በሳይንሳዊ ህጎች መካከል ያለውን ተፈጥሮ እና ልዩነት ምሳሌዎች በመስጠት አብራሩ።

4. ህብረተሰብ እና ባህል በሳይንሳዊ ምርምር ላይ እንዴት ተፅእኖ እንደሚያሳድሩ ወይም ተፅእኖ እንደማይኖራቸው ምሳሌዎችን በመስጠት አብራሩ።

5. የሳይንስ ሊቃውንት አይነ ህሊና እና የፈጠራ ችሎታ አይጠቀሙም ወይስ መቼ እና እንዴት ይጠቀማሉ? ምክንያታችሁን በምሳሌዎች አብራሩ።

6. የሳይንስ ሊቃውንት አንድ ወጥ የሆነ፣ ሁለንተናዊ ሳይንሳዊ ዘዴ ይከተሉ እንደሆነ ወይም የተለያዩ ዘዴዎችን ይጠቀማሉ የሚለውን ሃሳብ ምሳሌዎችን በመስጠት አብራሩ።

Appendix C Attitude towards physics laboratory

English Version

The main purpose of this questionnaire is to conduct a study focusing on the attitudes of pre-service physics teachers towards learning physics experiments. Dear pre-service physics teachers, you are cordially asked to cooperate by reading and understanding each statement. I would like to point out that the respondents' comments are for research purposes only, confidential and for no other purpose, and are based on the willingness of the respondents to complete the questionnaire. Many thanks and respect for your good cooperation.

Part 1: Description of the questionnaire participants

1) Full name: ____________________________ 2) Sex: __________ 3) Age: __________

4) Residence address where you completed high school: Urban ☐ Rural ☐

5) Educational Background: 10th complete ☐ 12th complete ☐ Certificate ☐ other _________

Part 2: Your attitude on learning physics experiments

These questionnaires consist of items prepared in the form of Likert-Scale to help the researcher explore pre-service physics teachers' attitude towards on learning physics experiments. These are 1 = Strongly Disagree, 2 = Disagree, 3 = Unable to Rate, 4 = Agree, 5 = Strongly Agree. Therefore, mark √ the level at which you believe it fits each idea.

No	Statement	Scale				
1	Physics laboratory does not frighten me	1	2	3	4	5
2	Physics laboratory lesson is among my likes	1	2	3	4	5
3	I like to study physics laboratory lesson in advance	1	2	3	4	5
4	I will use the things learnt during physics laboratory in my life	1	2	3	4	5
5	I feel tense while studying physics laboratory	1	2	3	4	5
6	I feel comfortable when I solve a new problem in physics laboratory	1	2	3	4	5
7	Trying to understand physics laboratory experiments is waste of time	1	2	3	4	5
8	There is no incentive side of physics laboratory studies	1	2	3	4	5
9	It is worth doing to learn physics laboratory experiments	1	2	3	4	5
10	It is not attractive to solve physics laboratory problems	1	2	3	4	5
11	Facing problems in physics laboratory, I try to solve them until I find the answer	1	2	3	4	5
12	I do not understand why some students enjoy physics laboratory	1	2	3	4	5
13	I do not take physics laboratory lesson if it is optional	1	2	3	4	5
14	While studying physics laboratory, I do not want to stop studying it	1	2	3	4	5
15	I usually take high marks from physics laboratory examinations	1	2	3	4	5
16	I am not worried about studying physics laboratory	1	2	3	4	5
17	I think that I cannot do physics laboratory experiment by myself	1	2	3	4	5
18	Succeeding in physics laboratory lesson is important for me	1	2	3	4	5
19	I rely on my knowledge about physics laboratory lesson	1	2	3	4	5
20	I enjoy talking about physics laboratory with others	1	2	3	4	5
21	I enjoy physics laboratory lesson	1	2	3	4	5
22	I do not want to hear even the name of physics laboratory	1	2	3	4	5
23	I do not want to take physics laboratory lesson	1	2	3	4	5
24	The lessons other than physics laboratory are more important for me	1	2	3	4	5
25	The topics in the physics laboratory confuse my mind	1	2	3	4	5
26	Physics laboratory is a boring lesson	1	2	3	4	5
27	Physics laboratory is one of the frightening lessons	1	2	3	4	5
28	I feel helpless while studying physics laboratory	1	2	3	4	5
29	Physics laboratory is not an interesting lesson for me	1	2	3	4	5
30	I would take more physics laboratory if I had that opportunity	1	2	3	4	5
31	I enjoy doing physics laboratory experiment by myself	1	2	3	4	5
32	Physics laboratory becomes more enjoyable if teachers do experiment	1	2	3	4	5
33	I hate physics laboratory lesson	1	2	3	4	5
34	I want to have an education based on physics laboratory	1	2	3	4	5

Amharic Version

ተ.ቁ	መግለጫ/ሃሳብ	የስምምነት ውሳኔ ደረጃ				
1	የፊዚክስ ላብራቶሪ አያስፈራኝም፡፡	1	2	3	4	5
2	የፊዚክስ ላቦራቶሪ ትምህርት ከምወዳቸው መካከል ነው፡፡	1	2	3	4	5
3	የፊዚክስ ላቦራቶሪ ትምህርትን አስቀድሜ ማጥናት እፈልጋለሁ፡፡	1	2	3	4	5
4	በፊዚክስ ላቦራቶሪ ትምህርት የተማርኩትን በሕይወቴ ውስጥ እጠቀመዋለሁ፡፡	1	2	3	4	5
5	የፊዚክስ ላብራቶሪ በማጠና ጊዜ ውጥረት ይሰማኛል፡፡	1	2	3	4	5
6	በፊዚክስ ላብራቶሪ ውስጥ አዲስ ችግር ስፈታ ምቾት ይሰማኛል፡፡	1	2	3	4	5
7	የፊዚክስ ላብራቶሪ ሙከራዎችን ለመረዳት መሞከር ጊዜ ማባከን ነው፡፡	1	2	3	4	5
8	የፊዚክስ ላቦራቶሪ ጥናቶች ምንም አይነት ጠንካራ ጎን የላቸውም፡፡	1	2	3	4	5
9	የፊዚክስ ላብራቶሪ ሙከራዎችን ለመማር በተግባር መስራት ጠቃሚ ነው፡፡	1	2	3	4	5
10	የፊዚክስ ላብራቶሪ ችግሮችን መፍታት ሳቢ አይደለም፡፡	1	2	3	4	5
11	በፊዚክስ ላቦራቶሪ ውስጥ ችግሮች ሲገጥሙኝ መልሱን እስከማገኝ ድረስ ችግሩን ለመፍታት እሞክራለሁ፡፡	1	2	3	4	5
12	አንዳንድ ተማሪዎች ለምን የፊዚክስ ላብራቶሪ እንደሚያስደስታቸው አይገባኝም፡፡	1	2	3	4	5
13	አማራጭ ከሆነ የፊዚክስ ላብራቶሪ ትምህርት መማር አልፈልግም፡፡	1	2	3	4	5
14	የፊዚክስ ላብራቶሪ በማጠናበት ጊዜ ጥናቴን ማቆም አልፈልግም፡፡	1	2	3	4	5
15	ብዙውን ጊዜ ከፊዚክስ ላቦራቶሪ ፈተናዎች ከፍተኛ ውጤት አገኛለሁ፡፡	1	2	3	4	5
16	የፊዚክስ ላብራቶሪ ማጥናት አያስጨንቀኝም፡፡	1	2	3	4	5
17	በግሌ የፊዚክስ ላብራቶሪ ሙከራ ማድረግ እንደማልችል አስባለሁ፡፡	1	2	3	4	5
18	በፊዚክስ ላቦራቶሪ ትምህርት ውስጥ ስኬታማ መሆን ለእኔ አስፈላጊ ነው፡፡	1	2	3	4	5
19	በፊዚክስ ላቦራቶሪ ትምህርት ባለኝ እውቀት እተማመናለሁ፡፡	1	2	3	4	5
20	ስለ ፊዚክስ ላቦራቶሪ ከሌሎች ጋር ማውራት ያስደስተኛል፡፡	1	2	3	4	5
21	የፊዚክስ ላቦራቶሪ ትምህርት ደስ ይለኛል፡፡	1	2	3	4	5
22	የፊዚክስ ላብራቶሪ ትምህርትን ስሙን እንኳን መስማት አልፈልግም፡፡	1	2	3	4	5
23	የፊዚክስ ላብራቶሪ ትምህርት መማር አልፈልግም፡፡	1	2	3	4	5
24	ከፊዚክስ ላብራቶሪ ትምህርት ውጭ ያሉት ትምህርቶች ለእኔ የበለጠ አስፈላጊ ናቸው፡፡	1	2	3	4	5
25	በፊዚክስ ላቦራቶሪ ትምህርት ውስጥ ያሉ ርዕሶች አእምሮዬን ግራ ያጋባሉ፡፡	1	2	3	4	5
26	የፊዚክስ ላቦራቶሪ አሰልቺ ትምህርት ነው፡፡	1	2	3	4	5
27	የፊዚክስ ላብራቶሪ ከአስፈሪ ትምህርቶች አንዱ ነው፡፡	1	2	3	4	5
28	የፊዚክስ ላብራቶሪ እያጠናሁ አቅመ ቢስነት ይሰማኛል፡፡	1	2	3	4	5
29	የፊዚክስ ላቦራቶሪ ለእኔ አስደሳች ትምህርት አይደለም፡፡	1	2	3	4	5
30	እድሉን ባገኝ የበለጠ የፊዚክስ ላብራቶሪ ትምህርት እወስድ ነበር፡፡	1	2	3	4	5
31	የፊዚክስ ላቦራቶሪ ሙከራ በራሴ ማድረግ ያስደስተኛል፡፡	1	2	3	4	5
32	የፊዚክስ ላቦራቶሪ በመምህራን ከተሰራ የበለጠ አስደሳች ይሆናል፡፡	1	2	3	4	5
33	የፊዚክስ ላቦራቶሪ ትምህርት እጠላለሁ፡፡	1	2	3	4	5
34	በፊዚክስ ላብራቶሪ ላይ የተመሠረተ ትምህርት ማግኘት እፈልጋለሁ፡፡	1	2	3	4	5

Appendix D Interview Protocol

D.1 Interview Questions for pre-service physics teachers

1. Have you noticed any differences between this laboratory and previous ones? Please explain.
2. Which type of laboratory mode do you prefer, the previous one or the current one? Please explain your reasons.
3. What are the advantages and disadvantages of this laboratory, in your opinion, and why?
4. How were you involved in the laboratory? Were there any differences in your participation compared to your previous experiences in a real laboratory setting? What was your interaction like with your peers, the teacher, and the laboratory technician?
5. Did this laboratory assist you in understanding the physics concept? If so, could you please explain which parts aided you?
6. What suggestions do you have for improving the new mode of laboratory experimentation?

D.2 Interview Questions for physics teachers & laboratory technicians

1. Have you felt any difference between this laboratory and those traditional/conventional laboratories you have done before? How do you compare? Please explain.

2. What do you think are the advantages and disadvantages of this mode of laboratory experimentations?

3. What are your comments and suggestions for further improvement of this mode of physics laboratory experimentation?

Appendix E Sample laboratory session

E.1 Blended Experiment Group Activity

Experiment Activity 1: Charging methods

Topic: Static Electricity

PhET Simulation name: *Balloons and Static Electricity*

Pre-laboratory Activities: How do you know the presence of charges? We can see sparks and hear cracking sounds when we remove woolen clothes in the dark. Why? Have you ever been shocked after walking on carpet and grabbing a door handle? Can charged objects put a force on each other from a distance? How?

Introduction/description of the topic: The description of the topic includes discussion of static electricity, electric charge, charging methods, and electric force.

Objectives of the experiment:-

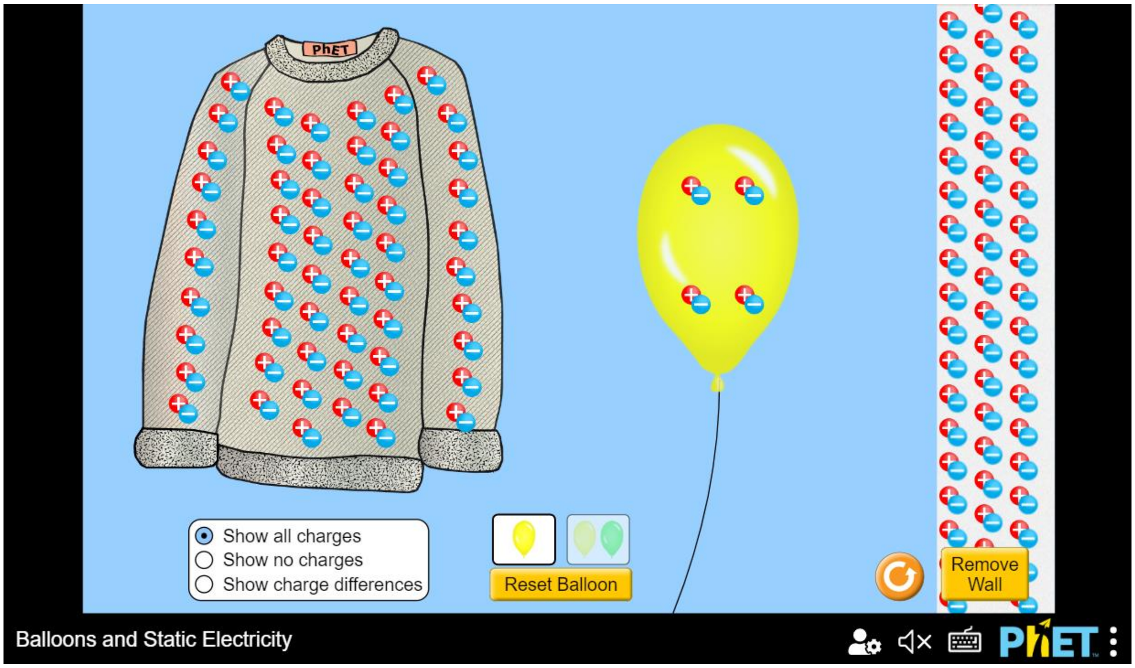
- Manipulate each charging method
- Describe the phenomena of charging by friction, conduction and induction.
- Illustrate models of charge distribution for friction, conduction and induction.

The learning objective of the experiment activity seeks for the affordances of both types of experiments. Utilizing both real and virtual experiments is necessary to achieve the objective of the experiment. For this experiment, both real experiments and virtual experiments should be used based on the learning objectives of the experiment. The choice was determined based on an analysis of the necessity for affordances. Preservice physics teachers should be able to observe and understand the phenomena of charging methods. The participants might not have much practical experience with charging methods beyond the theoretical concepts. Additionally, they will be exposed to certain attributes of a concrete material during the charging process. Real experiments are recommended for students who have little to no prior exposure to or knowledge with concrete materials, even if both real and virtual experiments offer for access to observation. On the other hand, it is impractical to observe in real life the phenomenon of the distribution of charge before and after the charging methods. In order to provide a representation of charges and their distribution, which are unseen objects, the PhET interactive simulation of *Balloons and Static Electricity* has been used.

a) **Materials needed for the virtual experiment:** *Balloons and Static Electricity* PhET interactive simulation.

Experimental set up and procedure

1. Go to the PhET simulations file and open *Balloons and Static Electricity*.
2. Once you open the file, begin by observing the simulation. For example, view *all charges*, *no charges* and *charge differences*.
3. Make observations about a balloon, a wall, and a sweater and reflect on the number of positive and negative charges on each.
4. Rub the balloon on the sweater and observe what happens when this charged balloon is close to the neutral wall.



5. Remove the wall, and use two balloons to explore repulsion and attraction. Explain how a balloon can be strongly or weakly attracted to the sweater.
6. Based on the investigation, extend the discussion to charging by conduction and induction.
7. How do you see the distribution of charges both during and after the charging process?

Note that: The model simplification of the interactive simulation offers insights to minimize misconceptions that can arise from the simulation. As a result, positive and negative charges are meant to give a relative idea of charge. Electrons are transferred or relocated, but not the protons.

The buoyant force acting on the balloons is intentionally not modeled in this simulation. The idea of staticness of charges in static electricity is misleading and may obscure many important ideas, including charge separation and density of unbalanced positive or negative charges. The participants should be aware of this issue in order to lessen misconceptions and enhance understanding.

a) **Materials needed for the real experiment:** 2 balloons, a thin string or thread, a woolen cloth such as swear, pieces of paper, and a wall

Experimental set up and procedure

1. Blow up one of the balloon, then attach a thin string or thread to it.
2. Hold the balloon so that your hand covers the smallest possible area of its surface.
3. Rub the balloon on the woolly object once, in one direction.
4. Holding the balloon up to the wall, with the side that was rubbed on the wool facing the wall, release it. Does the balloon remain adhered to the wall?
5. Repeat the above steps, but each time rub the balloon on the woolly item more often. What do you expect will happen if the balloon is positioned closer to the wall?
6. Hold a balloon by the thread and approach each of the materials, such as pieces of paper, with the balloon. Observe what occurs.
7. What conclusions can you draw from your data?

Post-laboratory activities: Discuss in detail the general features characterized by each of the charging methods. Observe and examine the behavior of the objects before and after the changing method. Explain how a balloon can be strongly or weakly attracted to the sweater. After rubbing the balloon on the sweater, how does the charge on the balloon compare to the charge on the sweater? What happens to the positive charges? What happens to the negative charges? Draw a picture.

Follow-up and assessment scheme

The physics teacher and the laboratory technicians should help preservice physics teachers to describe what they have just observed. The implementers of the intervention should help participants to communicate their results to the class and engage in group discussion.

E.2 Virtual Experiment Group Activity

Experiment Activity 1: Charging methods

Topic: Static Electricity

PhET Simulation name: Balloons and Static Electricity

Pre-laboratory Activities: How do you know the presence of charges? We can see sparks and hear cracking sounds when we remove woolen clothes in the dark. Why? Have you ever been shocked after walking on carpet and grabbing a door handle? Can charged objects put a force on each other from a distance? How?

Introduction/description of the topic: The description of the topic includes discussion of static electricity, electric charge, charging methods, and electric force.

Objectives of the experiment:-

- Manipulate each charging method
- Describe the phenomena of charging by friction, conduction and induction.
- Illustrate models of charge distribution for friction, conduction and induction.

Apparatus and materials needed: For this group of participants, the equipment and resources needed are entirely virtual. That is, except for computers to perform the PhET simulations, no real or physical materials are offered to this group. In a virtual environment, the computer displays the materials that need to be charged, the charges, and how they interact. All the circumstances that emerge in the experiment should be looked into by the students during the investigation. After completing the experiment, they are required to present their findings for discussion. The debate will be facilitated, assisted, and guided under the direction of the physics teacher educator.

Note that: The model simplification of the interactive simulation offers insights to minimize misconceptions that can arise from the simulation. As a result, positive and negative charges are meant to give a relative idea of charge. Electrons are transferred or relocated, but not the protons. The buoyant force acting on the balloons is intentionally not modeled in this simulation. The idea of staticness of charges in static electricity is misleading and may obscure many important ideas, including charge separation and density of unbalanced positive or negative charges. The participants should be aware of this issue in order to lessen misconceptions and enhance understanding.

Experimental set up and procedure

1. Go to the PhET simulations file and open Balloons and Static Electricity simulation.

2. Once you open the file, begin by observing the simulation.

3. Look at the balloon. Can you reflect on its charge?

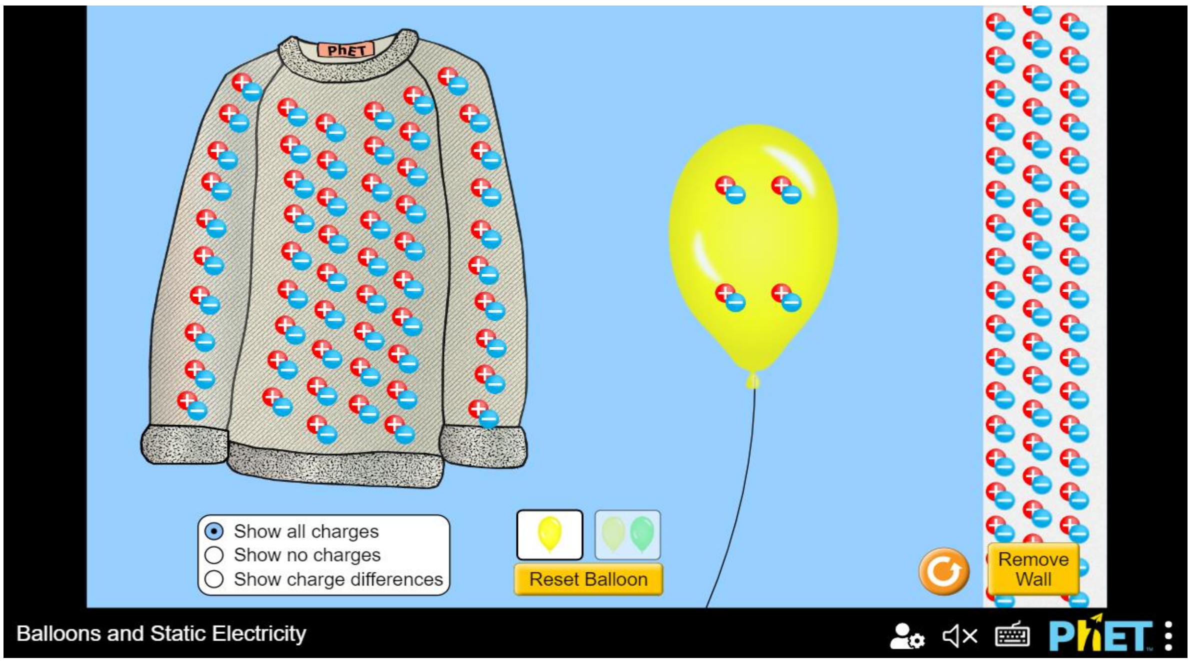
3. Play with the simulation for five minutes.

4. Make observations about a balloon, a wall, and a sweater that have positive and negative charges on each.

5. Rub the balloon on the sweater, remove the wall

6. By clicking on the button, you may choose to show all charges, show no charges, or show charge differences.

7. Fill the table based on your investigation.



Post-laboratory activities: Discuss in detail the general features characterized by each of the charging methods. Observe and examine the behavior of the objects before and after the changing method. What types of materials are charged by friction, conduction and induction? Hint: Conductors and Insulators.

Follow-up and assessment scheme

The physics teacher and the laboratory technicians should help preservice physics teachers to describe what they have just observed. The implementers of the intervention should help participants to communicate their results to the class and engage in group discussion.

E.3 Real Experiment Group Activity

Experiment Activity 1: Charging methods

Topic: Static Electricity

PhET Simulation name: Balloons and Static Electricity

Pre-laboratory Activities: How do you know the presence of charges? We can see sparks and hear cracking sounds when we remove woolen clothes in the dark. Why? Have you ever been shocked after walking on carpet and grabbing a door handle? Can charged objects put a force on each other from a distance? How?

Introduction/description of the topic: The description of the topic includes discussion of static electricity, electric charge, charging methods, and electric force.

Objectives of the experiment:-

- Manipulate each charging method
- Describe the phenomena of charging by friction, conduction and induction.
- Illustrate models of charge distribution for friction, conduction and induction.

Apparatus and materials needed: The equipment and materials required for this group of participants are all real. Two balloons, a light string or thread, a wool fabric, such as swear, and a wall are required items. The participants in this real experiment should execute and record their findings as they proceed. They must share their results for debate when the experiment is over. Under the guidance of the physics teacher educator and the laboratory technician, the discussion will be guided and promoted.

Note that: The idea of staticness of charges in static electricity is misleading and may obscure many important ideas, including charge separation and density of unbalanced positive or negative charges. The participants should be aware of this issue in order to lessen misconceptions and enhance understanding.

Experimental set up and procedure

1. Blow up one of the balloon, then attach a thin string or thread to it.
2. Hold the balloon so that your hand covers the smallest possible area of its surface.
3. Rub the balloon on the woolly object once, in one direction.
4. Holding the balloon up to the wall, with the side that was rubbed on the wool facing the wall, release it. Does the balloon remain adhered to the wall?
5. Repeat the above steps, but each time rub the balloon on the woolly item more often. What do you expect will happen if the balloon is positioned closer to the wall?
6. Hold a balloon by the thread and approach each of the materials, such as pieces of paper, with the balloon. Observe what occurs.
7. What conclusions can you draw from your data?

Post-laboratory activities: Discuss in detail the general features characterized by each of the charging methods. Observe and examine the behavior of the objects before and after the changing method. What types of materials are charged by friction, conduction and induction? Hint: Conductors and Insulators.

Follow-up and assessment scheme

The physics teacher and the laboratory technicians should help preservice physics teachers to describe what they have just observed. The implementers of the intervention should help participants to communicate their results to the class and engage in group discussion.

Appendix F: Experimental Activities of Phys 211 laboratory course

1. Charging methods
2. Measuring Current and Voltage
3. Ohm's Law
4. Factors affecting the resistance of a wire
5. Resistors in series and parallel combination
6. Determination of the direction of the magnetic field of a straight current carrying wire using compass needle
7. Electromagnets (this is a very simple experiment to identify whether a material is magnetic or nonmagnetic using battery, connecting wires, nail, probably compass needle)
8. Electromagnetic Induction
9. Electromotive force and internal resistance

Appendix G: PhET's approach to guided inquiry activities

Creating PhET Interactive Simulations Activities: PhET's Approach to Guided Inquiry

In order to productively support student exploration, PhET suggests activities which use guided inquiry enabling students to construct their own understanding:

1. **Define specific learning goals**
   The learning goals need to be specific and measurable. It is important that the activity goals are well-defined for your particular standards and student population because each sim is designed to support many possible learning goals.
2. **Give only minimal directions on sim use**
   The sims are designed and tested to encourage students to explore and use sense making. Recipe-type directions can suppress active thinking, resulting in a focus on following directions and answering questions correctly. For example, in a sim about motion, avoid instructions such as "set the gravity to zero;" instead provide a challenge like, "Find out what affects the speed of the Skater."
3. **Connect and build on students' prior knowledge & understanding**
   Ask questions to elicit student ideas about the topic. For example, to start using a sim about dissolving ask: "What might happen if you add a lot of salt to water?" and "Do you think it matters what solid you add to water?" Guide students to use the simulation, and discussion with their partner, to test those ideas and resolve any inconsistencies.
4. **Encourage students to use sense-making and reasoning**
   The sims are designed to help students develop and assess their understanding and reasoning about science topics. The activity should be geared towards encouraging the student to operate in learning mode not performance mode. Emphasize questions that require making sense of the simulation topic and ideas, using words and diagrams, rather than questions with right/wrong answers. For example, "Design an experiment to see what relationships you can find between how hard you push a box and how fast it will move. Make a data table and a graph to help explain your ideas," and "How might your graph change if the box had a person sitting on it? Explain your reasoning."
5. **Connect to and make sense of real-world experiences**
   Students learn more when they can see that science is relevant to their everyday life. The sims often use images from everyday life, but where possible the activity should explicitly help them relate science to their personal experience. As you write questions, consider their interests, age, gender, and ethnicity and use friendly language. For example, when using a simulation that uses a sandwich metaphor for balancing chemical equations, you might ask, "If you were talking to your friend, Rose, about making sandwiches, what would you tell her to do to figure out how many sandwiches she can make from 10 pieces of bread?"
6. **Design collaborative activities**
   The sims provide a common language and experience for students to collaboratively construct their understanding. Students can learn more when they communicate their ideas and reasoning to each other. Have students work in pairs or groups. Encourage students to share their ideas with their partner, working together to answer questions. Invite students to share ideas during whole class discussions.
7. **Help students monitor their understanding**
   Provide opportunities for students to check their own understanding. One way is to ask them to predict something based on their new knowledge and then check the prediction with the simulation.

Appendix H: Letter of permission for the study

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ሥነ-ትምህርትና ባሕሪይ ጥናት ኮሌጅ
የሳይንስና ሒሳብ ትምህርት ክፍል
አዲስ አበባ፣ኢትዮጵያ

Addis Ababa University
College of Education and Behavioral Studies
Department of Science and Mathematics Education
Addis Ababa, Ethiopia

Date: Semptember 23, 2020
Ref. No.: SMED/250/2013-20

To: ______________________ College of Teacher Education

From: Mulugeta Atnafu (PhD)
Chairman, Department of Science and Mathematics Education

Subject:- <u>Support</u>

As part of the PhD studies, Mr. Zemenu Miheret has selected your college as one of his research sites. Accordingly, he will be taking a number of engagements such as data collection through various approaches. Hence, our Department would like your College to support him in executing his doctoral studies through the provisions. We would like to thank in advance for the support rendered.

With regards,

C.C.

- Mr. Zemenu Miheret
  PhD Candidate

☎ 011 1 22 07 67 ✉ 1176

Appendix I: Permission of data gathering instruments (conceptual tests)

My request to use assessment tools was approved by PhysPort, which was developed by the American Association of Physics Teachers, through email, as can be seen below.

Asking for assessment instruments Inbox x

Zemenu Mihret <zmihret@gmail.com> Sep 29, 2020, 9:12 PM
to editor

Dear Sir/Madam, Dear Sir/Madam, i am a PHD student at Addis Ababa University in Physics Education. I am working on my PhD and need assessment instruments regarding conceptual and procedural knowledge of electricity and magnetism concepts. Would you please help me access these instruments/tests? Thank you in advance.

Zemenu Mihret Zewdie
Lecturer in Physics, Injibara College of Teacher Education
* PhD Candidate at AAU, Department of Science and Mathematics Education (Physics)
Mobile (251) 912 417628
zmihret@gmail.com <zmihret@gmail.com>

Educator Status Verified

PhysPort Verification Staff <verification@physport.org> Fri, Oct 2, 2020, 6:16 PM
to me, verification

Dear Zemenu Mihret,

Congratulations! You've been approved as a verified educator at www.physport.org. You may now download assessments from www.physport.org/assessments/ using your zmihret@gmail.com account.

PhysPort: Unlimited downloads approved Inbox x

PhysPort Verification Staff <verification@physport.org> Tue, Nov 10, 2020, 12:53 AM
to me, verification

Dear Zemenu Mihret,

Thanks for your response. You are now approved to download unlimited assessments from www.physport.org/assessments/ using your zmihret@gmail.com account.

Sincerely,

Sarah "Sam" McKagan

Director, PhysPort: www.physport.org
American Association of Physics Teachers