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**AKBOPE AIDOS**

**“Integration of interactive online resources in teaching chemistry  
laboratory courses”**

**7M01502 – Chemistry**

**MASTER’S DEGREE DISSERTATION**

**Kaskelen, 2025**

Faculty of Education and Humanities  
Department of Pedagogy of Natural Sciences

"Admitted to defense":

Head of Department

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MASTER'S DEGREE DISSERTATION

Integration of interactive online resources in teaching chemistry  
laboratory courses

7M01502– Chemistry

Student: Aidos Akbope Aidos

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Kaskelen, 2025

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## ABSTRACT

In the context of digitalization of education, there is an increasing need to find effective forms and methods of teaching, especially in natural science disciplines, where laboratory classes play a key role. The purpose of this study was to study the impact of the integration of interactive online resources such as virtual laboratories and educational videos on the preparation of students to perform laboratory work in chemistry.

The study involved teachers and undergraduate students studying in the fields of Chemistry and Biology. A quasi-experimental approach, questionnaires, and comparative analysis of the results of pre- and post-tests were used. Three forms of pre-laboratory training were identified: traditional (instruction + explanation + video), video demonstration and virtual simulation. Statistical processing included factor analysis, single-factor analysis of variance (Welch's ANOVA), as well as the interpretation of averages and the significance of differences between groups.

The results showed that the use of virtual laboratories has a positive effect on the formation of applied laboratory skills, especially among undergraduates. Teachers with experience working with digital tools demonstrated higher confidence and a positive attitude towards their use. The greatest effect was achieved by combining various forms of pre-laboratory training.

The study confirms the effectiveness of a blended approach in teaching laboratory chemistry courses and highlights the need for methodological and technical support from teachers for the successful implementation of digital solutions in the learning process.

**Keywords:** *virtual laboratories, video demonstrations, chemical education, pre-laboratory training, interactive resources, blended learning.*

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## АННОТАЦИЯ

В условиях цифровизации образования возрастает потребность в поиске эффективных форм и методов преподавания, особенно по естественнонаучным дисциплинам, где лабораторные занятия играют ключевую роль. Целью данного исследования было изучение влияния интеграции интерактивных онлайн-ресурсов, таких как виртуальные лаборатории и обучающие видеоролики, на подготовку студентов к выполнению лабораторных работ по химии.

В исследовании приняли участие преподаватели и студенты старших курсов, обучающиеся по специальностям химия и биология. Был использован квази экспериментальный подход, анкетирование и сравнительный анализ результатов предварительного и пост тестового тестирования. Были определены три формы предлабораторной подготовки: традиционная (инструкция + объяснение + видео), видео демонстрация и виртуальное моделирование. Статистическая обработка включала факторный анализ, однофакторный дисперсионный анализ (дисперсионный анализ Уэлча), а также интерпретацию средних значений и значимости различий между группами.

Результаты показали, что использование виртуальных лабораторий положительно влияет на формирование прикладных лабораторных навыков, особенно у студентов старших курсов. Преподаватели, имеющие опыт работы с цифровыми инструментами, продемонстрировали более высокую уверенность и позитивное отношение к их использованию. Наибольший эффект был достигнут при сочетании различных форм предлабораторной подготовки.

Исследование подтверждает эффективность смешанного подхода в преподавании лабораторных курсов химии и подчеркивает необходимость методической и технической поддержки со стороны преподавателей для успешного внедрения цифровых решений в учебный процесс.

**Ключевые слова:** *виртуальные лаборатории, видео демонстрации, химическое образование, предлабораторная подготовка, интерактивные ресурсы, смешанное обучение.*

## АНДАТПА

Білім беруді цифрландыру жағдайында оқытудың тиімді формалары мен әдістерін, әсіресе зертханалық сабақтар шешуші рөл атқаратын жаратылыстану пәндерінде іздеудің қажеттілігі артып келеді. Бұл зерттеудің мақсаты виртуалды зертханалар мен оқу бейнелері сияқты интерактивті онлайн ресурстарды біріктірудің студенттерді химия пәнінен зертханалық жұмыстарды орындауға дайындауға әсерін зерттеу болды.

Квази-эксперименттік тәсіл, сауалнамалар, алдын - ала және кейінгі сынақтардың нәтижелерін салыстырмалы талдау қолданылды. Зертханаға дейінгі оқытудың үш формасы анықталды: дәстүрлі (нұсқаулық + түсіндіру + видео), бейне-демонстрация және виртуалды модельдеу. Статистикалық өңдеуге факторлық талдау, дисперсияның бір факторлы талдауы (Welch ` s ANOVA), сондай-ақ орташа мәндерді түсіндіру және топтар арасындағы айырмашылықтардың маңыздылығы кірді.

Нәтижелер виртуалды зертханаларды пайдалану қолданбалы зертханалық дағдыларды қалыптастыруға, әсіресе магистранттар арасында оң әсер ететіндігін көрсетті. Цифрлық құралдармен жұмыс істеу тәжірибесі бар мұғалімдер жоғары сенімділік пен оларды қолдануға деген оң көзқарасты көрсетті. Ең үлкен нәтижеге зертханаға дейінгі дайындықтың әртүрлі формаларын біріктіру арқылы қол жеткізілді.

Зерттеу зертханалық химия курстарын оқытудағы аралас тәсілдің тиімділігін растайды және оқу процесіне цифрлық шешімдерді сәтті енгізу үшін мұғалімдердің әдістемелік және техникалық қолдау көрсету қажеттілігін көрсетеді.

**Кілт сөздер:** *виртуалды зертханалар, бейне демонстрациялар, химиялық білім беру, зертханаға дейінгі дайындық, интерактивті ресурстар, аралас оқыту.*

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## **LIST OF ABBREVIATIONS**

**VL** – Virtual Laboratory

**LMS** - Learning Management Systems

**IT** – Information Technology

**IOLR** – Interactive Online Laboratory Resources

**TPACK** - Technological Pedagogical Content Knowledge

**MSQs** - Multiple Select Questions

**EFA** - Exploratory Factor Analysis

**IBL** – Inquiry Based Learning

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## INTRODUCTION

Chemistry is a major focus of modern science and technology, influencing industries ranging from pharmaceuticals and materials to energy and environmental sciences. As a discipline with deep theoretical and practical roots, the teaching of chemistry requires an integrated approach that combines classroom instruction with hands-on laboratory activities. These laboratory activities are not simply an adjunct to theoretical lessons; they are fundamental to fostering a comprehensive understanding of chemical concepts, experimental techniques, and scientific methodologies (Hofstein & Lunetta, 2004). This thesis examines evolving methodologies in chemistry education, particularly the integration of interactive online resources into laboratory instruction, with a particular focus on the exploration of various virtual laboratories and simulations.

The statements were developed to assess instructors' confidence, readiness, perceptions, and infrastructure access concerning the integration of interactive online resources in laboratory teaching. The questionnaire focused on understanding how instructors perceive the benefits and challenges of integrating virtual lab simulations and video-based instruction, their experience in using these resources, and their opinions on the potential impact on students' learning outcomes.

### **Relevance of the study**

The integration of online resources into laboratory teaching is in line with broader trends in educational innovation. Virtual labs, simulators, and digital teaching aids have gained popularity as a valuable complement to physical labs. These tools offer unique advantages such as the ability to visualise molecular interactions, repeat experiments without resource constraints, and meet a variety of learning needs. Moreover, the COVID-19 pandemic highlighted the importance of such resources to ensure educational continuity during disruptions (Seery et al., 2021).

Despite the recognized potential of interactive online resources, their adoption in laboratory work remains uneven and challenging. Traditional laboratory work often emphasizes tactile skills and real-world problem - solving that are difficult to replicate in a virtual environment. In addition, differences in access to technology and internet connectivity create significant barriers, especially in resource-limited settings. There is also a need for comprehensive research on the effectiveness of these tools to achieve learning outcomes comparable to or superior to those of traditional methods (Ma and Nickerson, 2006).

Inclusion is another important issue. Students with disabilities or from low-income communities face unique challenges in accessing and benefiting from traditional laboratory instruction. Online resources promise to bridge these gaps, but

their design and implementation must be based on principles of universal access and equity (Burgstahler, 2015).

### **Aim and objectives of the study**

*Aim:* to investigate the integration of interactive online resources - such as virtual lab simulations and video-based instruction - into teaching chemistry laboratory courses, and to assess their impact on students' laboratory performance and learning outcomes compared to traditional methods.

### **Objectives:**

- To identify the key factors that influence the effectiveness of interactive online resources in chemistry laboratory teaching.
- To examine how these factors vary with teacher characteristics, such as prior experience with digital tools and academic qualifications.
- To explore the factors that shape students' experiences with interactive online resources in chemistry lab settings.
- To analyze how students' experiences vary based on their characteristics and identities, including academic year level and gender.
- To compare the effectiveness of interactive online resources and traditional teaching methods in improving students' laboratory performance.
- To assess the impact of students' prior knowledge on the effectiveness of different pre-laboratory preparation formats (traditional, video, virtual lab).

### **Research Questions**

1. What factors influence the effectiveness of interactive online resources in chemistry laboratory teaching, and how do these factors vary with teacher characteristics?
2. What factors shape students' experience with interactive online resources in chemistry labs, and how do these factors vary by student characteristics and identities?
3. How do interactive online resources compare to traditional methods in impacting students' chemistry lab performance, considering their prior knowledge?

### **Research hypothesis**

1. The effectiveness of interactive online resources in chemistry laboratory teaching depends on teacher characteristics such as teaching experience, digital competence, and attitudes toward technology.
2. Students' conceptual understanding, laboratory skills, and engagement with interactive online resources differ based on their characteristics and identities, including year level and gender.

3. Students who use interactive online resources for pre-lab preparation perform better in chemistry laboratory tasks than those who use traditional preparation methods, when prior knowledge is taken into account.

### **The significance of the study**

This study is important for several reasons. Firstly, it addresses the growing need for innovative teaching methods that meet the technological advances and requirements of modern education. By evaluating the role of online resources in laboratory teaching, this study contributes to the discussion on improving chemistry education. Second, the findings have practical implications for educators, policy makers, and institutions seeking to improve the accessibility and effectiveness of laboratory instruction. Finally, the study provides insights into how online resources can fill gaps in resource-limited settings, ensuring equitable access to quality education.

The findings provide important information about the effectiveness of digital resources in laboratory teaching. While traditional preparation methods (written procedures, explanations, and YouTube videos) are well-established, the study shows that virtual lab simulations and video-based resources can be promising alternatives, especially in distance learning or limited-access environments.

The surveys with instructors and students give additional insights into how these resources are perceived and accepted in real teaching settings. This helps teachers and education policymakers understand not just the test results, but also how ready and motivated students and teachers are to use online resources.

Finally, the study highlights that students' prior knowledge is an important factor for success in laboratory learning. This finding supports the idea that teachers should consider students' starting knowledge and tailor pre-laboratory activities to meet their needs.

Overall, this study contributes to improved laboratory teaching practices by demonstrating how blended approaches combining traditional methods with modern online resources can enhance learning outcomes and engagement in chemistry education.

**Outline of the thesis.** The content of this thesis as follows:

Chapter 1 presents a comprehensive literature review, beginning with the role of laboratory work in chemistry education, followed by the emergence of digital tools and interactive resources, and a comparison of different instructional approaches. It also introduces the theoretical frameworks guiding the study.

Chapter 2 describes the methodology, including the research design, participants, data collection instruments, procedure, and analysis techniques.

Chapter 3 reports the results and findings, including analyses of both teacher and student data.

Chapter 4 provides a discussion of the findings in relation to the literature and theoretical framework. The thesis concludes in

Chapter 5, summarizing the key outcomes, outlining limitations, and offering suggestions for future research.

Additional materials such as references and appendices are provided at the end.

# LITERATURE REVIEW

## 1.1 The role of laboratory work in chemistry education

Laboratory practice is one of the core elements of chemistry studies and is also essential in developing professional competence. Laboratory work assists in deeper absorption of the theoretical content, shapes practical laboratory technique, is developing thinking, and acquiring the ability to apply the acquired knowledge in practice.

In performing laboratory exercises, students are able to directly observe chemical processes, which makes their understanding more profound. Practical work makes up the methodology of research by the students, ability to design an experiment, perform observations, analyze and interpret the results.

Virtual laboratory environments have emerged as a potential solution to the faced problem. By offering students a simulated laboratory experience that can be accessed online. Virtual laboratories or laboratory simulations have been used for two main purposes in chemistry education. Firstly, they have been used to provide students with visual representations of chemistry concepts, and secondly, they have been used to prepare students for their laboratory sessions. (Dalgarno, Bishop, Adlong, Bedgood Jr., 2009, 854). Also, learning platforms and multimedia resources allow students to visualize and interact with the feelings that will be experienced during experiments, improving their understanding of the traditional laboratory environment.

Current trends in chemistry teaching are centered on the competency model in which laboratory tuition not only serves to learn curricular material, but also to complement super subject qualities including critical thinking, teamwork, adherence to safety procedures and to scientific ethics. Laboratory work thus represents a significant instrument in developing not just topical but also universal competence, which makes laboratory studies an essential element in educating tomorrow's specialists in chemistry.

### ***Traditional approaches to chemistry lab teaching***

Chemistry, as one of the central sciences, relies heavily on laboratory experiments to connect theory to practice. Laboratory exercises in chemistry education play an important role in developing students' understanding of complex chemical principles, problem-solving skills and scientific thinking. Hands-on activities help students appreciate the technique and methodology of experimentation, which is an integral part of science.

Chemistry laboratory activities have long been a cornerstone of science education, going back to the nineteenth century. Early approaches were based on verification-type experiments in which students performed certain activities to confirm

known theories (Johnstone & Al-Shuaili, 2001). Traditional methods were often successful in introducing basic concepts and techniques, but limited opportunities for creativity and critical thinking. The rigid structure of the 'cookbook' experiment prevented students from exercising autonomy in the process of hypothesising, developing and interpreting data (Domin, 1999).

The twentieth century saw a gradual shift to more student-centred approaches in laboratory teaching. One strong pillar was Inquiry-Based Learning, where students were required to explore a scientific question and design an experiment without much instruction. This method allowed for a deeper understanding of how science works and developed critical thinking skills. For example, IBL-based laboratory activities have been shown to increase students' ability to connect theoretical knowledge with real-life applications (Lazonder & Harmsen, 2016).

Several pedagogical theories underlie laboratory activities in chemistry education. Constructivist approaches emphasise active learning and student engagement. In this regard, constructivism argues that students learn better by making meaning of scientific concepts for themselves through experience and reflection. The laboratory becomes a context in which active learning is realised through manipulating variables, observing what is happening and drawing conclusions from these observations using empirical data.

In addition to constructivism, the use of laboratory activities in chemistry teaching also draws on experiential learning theory. Kolb's model of experiential learning - concrete experience, reflective observation, abstract conceptualisation and active experimentation - finds close parallels in the structure of many laboratory activities (Kolb, 1984). Students participating in each phase of the experiential learning cycle develop a comprehensive understanding of chemical phenomena and their underlying principles.

Laboratory activities in chemical education are numerous, and some range from simple demonstrations to more complex open-ended investigations. A typical example is titration, which is usually carried out to determine the unknown concentration of a solution. It not only introduces fundamental concepts such as molarity and stoichiometry, but also helps students to develop precision and accuracy of measurement.

Other examples include the synthesis of aspirin, a multi-step experiment that introduces students to organic chemistry techniques including recrystallisation and determination of melting point. Laboratory work and real-life connections are important in this work because aspirin synthesis parallels procedures used in pharmaceutical companies, as cited in Niaz, 2008.

Recently, laboratory work has been designed according to the principles of green chemistry. For example, microscale experiments reduce waste and limit exposure to hazardous chemicals, thereby addressing environmental concerns. In an educational setting, microscale techniques are of particular importance because of their safety and resource-saving nature (Anastas & Warner, 1998).

### ***Challenges in providing effective laboratory education***

Despite the recognised benefits of laboratory classes, there are still a number of challenges in their delivery. Most often, limited resources, including equipment and consumables, constrain the scope and quality of laboratory instruction. Large class sizes further limit individualised feedback and support, which reduces the effectiveness of hands-on learning (Hofstein & Mamlok-Naaman, 2007).

Serious safety concerns are also relevant. Chemistry laboratories include harmful chemicals and equipment, so safety must be given serious consideration. Training and ensuring proper supervision for all students remains paramount when conducting laboratory activities.

Another challenge is the alignment of laboratory activities with the objectives of the curriculum. Sometimes laboratory activities are seen as an additional rather than an integral part of the learning process, resulting in a disconnect between the theoretical and practical aspects of chemistry education. This problem requires thoughtful curriculum design that effectively integrates laboratory activities into the overall framework of chemistry education.

Laboratory activities play an important role in chemistry education; they provide many opportunities for students to apply theoretical knowledge, develop practical skills, and engage in scientific inquiry. The evolution of laboratory teaching methods, from traditional test experiments to inquiry-based and experiential approaches, reflects the increasing emphasis on active learning and student engagement. This presents challenges related to resource constraints, safety, and curriculum alignment, not to mention important student learning outcomes. In this context of continuous innovation and adaptation by chemistry teachers, laboratory experiments must take centre stage as an important component of science education.

## **1.2 Emergence of digital tools and interactive resources in education**

The improvement of multimedia training tools is driving the modernization of the entire educational process: lectures are held in presentation mode, interactive methods of presenting educational materials are used in practical and seminar classes, tests and exams are taken using machine control. The most conservative part of the educational process remains laboratory workshops, and the expediency of their complete transfer to virtual mode is not yet completely clear.

When studying chemistry in some cases, modern technologies allow you to move away from the actual conduct of chemical processes without losing the quality of the information received. The need for virtual laboratory work arises mainly in correspondence and distance education, as well as when students work out missed classes, lack of sophisticated equipment and expensive or inaccessible reagents. In addition, for some professions, the possibilities of a computerized laboratory workshop are wider than in a traditional one. Thus, students have the opportunity to study reactions with substances that are prohibited for use in the educational process, such as mercury and arsenic compounds. In addition, with such a setting of the workshop there are no time restrictions, the student can perform (or prepare) tasks during extracurricular time, and they can be repeated several times.

The integration of online resources into chemistry education has made the teaching of laboratory courses more accessible, interactive, and flexible. These tools provide unprecedented opportunities for students to visualise complex concepts, conduct virtual experiments and work with course materials outside of traditional laboratories. Online resources - from virtual labs to simulation software - have become indispensable in today's educational scenario to address resource constraints, diverse learning needs and shocks such as the COVID-19 pandemic.

The COVID-19 pandemic highlighted the role of online resources in continuing education. During the lockdown, virtual labs and simulations became the primary tools for lab sessions. Since then, blended learning models that combine traditional and online modes have found their place as a more sustainable approach to education. For example, students can use virtual labs to prepare for physics experiments, making efficient use of time and lab resources.

Online resources have changed the educational landscape in chemistry, offering solutions that were previously long considered unsolvable. Complementing practical work, these tools provide greater access, visualisation and flexibility to better meet the diverse needs of students. However, their shortcomings highlight the need for an integrated approach that incorporates both online and physical methods. As technology continues to evolve, the potential for online resources to complement chemistry education will also grow and therefore place it at the centre of a range of contemporary pedagogical strategies.

The use of online tools in chemistry teaching has evolved from a supplementary aid to a crucial component of laboratory classes. While early tools such as instructional videos and animations helped students visualise and better understand abstract chemical processes, more recently interactive simulations and virtual labs have emerged. For example, resources such as PhET Interactive Simulations and ChemCollective allow students to study chemical reactions, equilibrium and kinetics

in a virtual but non-harmful environment. The resources have been created for different modes of learning: guided or exploratory, depending on which one the student feels best helps them deepen their knowledge.

### 1.2.1 Online simulation and virtual labs

Modern digital technologies provide great opportunities for modernization of the chemistry teaching process, especially in terms of laboratory works. Digital tools make it possible to reproduce experimental activities in an interactive form, which promotes deeper learning of theoretical material, development of practical skills and formation of research competence. Below we discuss how each of the tools – simulations, virtual laboratories and educational platforms – can be applied in teaching chemistry laboratory courses.

A simulation is a digital model of a real or hypothetical process, system or phenomenon designed to simulate conditions in which learners can observe, experiment and make decisions without risk to health or equipment. In educational practice, simulations allow the reproduction of complex scientific processes (e.g., chemical reactions, biological mechanisms, physical phenomena) that are impossible or difficult to reproduce in a real laboratory.

Simulations promote analytical thinking, understanding of relationships between variables, and learning practical skills in a safe digital environment. Simulations allow the modeling of chemical processes and phenomena, including those that are impossible or difficult to reproduce in a real laboratory (e.g., explosive, toxic, or expensive reactions).

Applications in teaching:

- Visualization of microscopic processes (molecular interactions, ionic exchanges, intermolecular forces);
- Simulation of reactions with the possibility of changing parameters (temperature, pressure, concentration);
- Preparing students for real experiments through step-by-step playback of procedures.

Benefits:

- Increases visibility and understanding of complex concepts;
- Safety: eliminates contact with hazardous substances;
- Ability to repeat the experience multiple times.

Example: Using PhET Interactive Simulations to demonstrate acid-base reactions.

A virtual laboratory is an interactive digital environment where students can conduct laboratory experiments online. It includes a set of tools, models and tasks that

allow us to perform activities similar to those performed in a traditional laboratory: measuring, mixing substances, observing reactions, etc.

Virtual laboratories are especially relevant in distance learning, as well as in conditions of limited access to laboratory equipment. They provide safety, accessibility and the possibility of multiple repetition of experiments, which contributes to a deeper learning of educational material.

The virtual laboratory is an interactive digital environment that simulates real laboratory conditions. It allows students to perform experiments using virtual equipment, reagents and instrumentation.

Application in teaching:

- Replacing or supplementing traditional laboratory classes in distance learning;
- Developing skills in experiment planning, data collection and processing;
- Practicing titration, synthesis, chromatography and other laboratory procedures.

Advantages:

- High accessibility: does not require physical presence in the lab;
- Possibility of individualized pace of assignments;
- Automated result checking and feedback.

Example: Using PraxiLab to study organic synthesis or water analysis.

An educational platform is a digital system (website, application or software package) designed to organize, deliver and support the learning process. Educational platforms provide access to learning materials, tests, assignments, feedback tools and learning analytics. Examples of such platforms are Moodle, Google Classroom, Khan Academy, PhET, Labster and others.

Platforms can include both theoretical and practical components (e.g. simulations and virtual laboratories), providing a comprehensive digital learning environment. Educational platforms (LMS - Learning Management Systems) are complex systems for organizing the educational process. They include hosting learning materials, tests, video lessons, simulations, virtual laboratories and assessment systems.

Learning Applications:

- Posting lab instructions, video experiences and presentations;
- Integrate with simulations and virtual labs;
- Provide communication between instructor and student;
- Monitor progress and automate reporting.

Benefits:

- Centralized access to materials;
- Support for asynchronous and synchronous learning;
- Ability to individualize educational trajectory.

Examples of platforms: Moodle, Google Classroom, Microsoft Teams, Zoom + Labster/PhET integration.

### **1.2.2 Effectiveness of online resources in science education**

Modern education is undergoing an active digitization process, which is particularly evident in the teaching of natural sciences such as chemistry, biology, physics and ecology. In this regard, online resources are growing in importance and are becoming an integral part of the educational process. Online resources include a variety of digital tools, from learning platforms and virtual labs to interactive simulations and video lectures. The use of these tools expands the pedagogical capacity of teachers, diversifies the presentation of teaching materials and activates the cognitive activity of students.

One of the main advantages of online resources is their accessibility. Students can interact with the learning material at their own pace and at their convenience, which is especially important when studying difficult topics. In addition, many online resources offer visualizations, animations, and step-by-step simulations to give students a deeper understanding of complex scientific processes. This is especially important when opportunities for distance learning or face-to-face lab sessions are limited.

Online learning also helps to develop key student competencies such as independence, information literacy, critical thinking and digital literacy. The use of digital resources can be effective in developing students' research skills: formulating hypotheses, setting goals, analyzing data, and interpreting results. At the same time, students develop a more stable interest in the subject and increase the level of participation in the educational process.

The digital educational resources can serve as an effective complement to traditional teaching methods, especially within the framework of blended and distance learning formats. The integration of digital educational resources into educational environments contributes to the personalization and individualization of learning, also taking into account the different levels of training and learning styles of each student.

It should be noted that the effectiveness of online learning resources depends to a large extent on the correct selection and methodical integration of these tools into the learning process. Teachers must take into account the pedagogical objectives, the level of preparedness of the students and the technological capabilities of the educational organization. Thus, online resources are not a foolproof substitute for traditional learning, but if used properly, they can greatly improve the quality and effectiveness of learning.

Against the background of the rapid development of digital technologies and the growing need to adapt the educational process to modern requirements, the effective use of online resources is becoming one of the most important conditions for improving the quality of education in the field of natural sciences. They allow the implementation of practice-oriented methods, expand the possibilities of conducting virtual experiments, contribute to the formation of sustainable learning strategies and the development of scientific thinking among students.

Another strong advantage of online resources relates to the concept of accessibility. Students can access virtual labs and simulations from anywhere, eliminating the need to set up expensive labs. Especially useful when an institution is under-resourced, or during outages such as lockdowns, online tools allow students to practice repeatedly, allowing for personalised learning at their own pace or re-learning an under-learned concept.

One more advantage is better visualization of chemical phenomena. Simulations give students the opportunity to observe molecular interactions, reaction mechanisms and energy changes, which cannot be done in traditional labs. This visual approach promotes deeper understanding and better reinforcement of concepts. For example, molecular modelling software such as Spartan and Avogadro allows the construction and analysis of molecular structures, developing a much more intuitive understanding of chemical bonding and geometry.

### **1.2.3 Challenges and limitations of using online platforms/simulations/virtual labs in laboratory teaching**

Despite the significant potential of digital technologies in teaching chemistry and other natural sciences, their introduction into laboratory practice is accompanied by a number of challenges and limitations. Online platforms, simulations, and virtual laboratories are designed to empower teachers and students, but in practice, their use requires consideration of many factors: technical, pedagogical, methodological, and psychological. The main problems faced by educational institutions, teachers, and students when using digital tools in the context of laboratory learning are discussed below.

One of the key problems with the introduction of online formats is the disparity in technical support. Not all students have access to a stable internet connection, modern computers, or mobile devices capable of working with high-load platforms or 3D environments. This problem is especially acute in remote regions and rural areas. In addition, some simulations and virtual labs require the installation of special software or work through browsers that are incompatible with older versions of operating systems.

Also, educational institutions may lack IT specialists who can provide technical support or quickly eliminate failures. This is especially critical when conducting synchronous classes or online exams, where failures can affect the objectivity of student knowledge assessment.

Digital tools require a revision of traditional teaching methods. Teachers need to adapt curricula, rework instructions for laboratory work, and develop new forms of monitoring and evaluation. Virtual experiments often do not meet the standard requirements of educational programs, and teachers are forced to spend additional time searching for suitable resources, adapting them, and integrating them into the learning process.

In addition, virtual laboratories do not always reflect the full experimental reality. For example, students may not encounter such important aspects of working in a real laboratory as safety, working with real equipment, preparing solutions, weighing substances, etc. Thus, the reproducibility and realism of digital models may be limited.

One of the main disadvantages of virtual laboratories and simulations is the limited development of motor and practical skills. In the course of real laboratory work, students learn how to accurately measure, work with chemical glass, use scales, and manipulate reagents. In a virtual environment, these actions are replaced by mouse clicks, which reduces sensorimotor involvement and does not create the necessary level of professional readiness.

As a result, graduates who have studied primarily in a digital environment may have difficulty transitioning to practical work in a real laboratory, especially if it comes to chemical analysis or manufacturing.

Laboratory classes traditionally contribute to the development of teamwork, communication and cooperation between students. Virtual formats limit live interaction, make it difficult to exchange opinions, discuss results, and make decisions together. This is especially important for the training of future specialists, whose work in the future will depend on the ability to effectively interact in a team.

Although some platforms offer built-in chats and video calls, they are not a substitute for full-fledged physical presence and emotional contact, which reduces the level of engagement and motivation of students.

Distance learning and virtual learning formats can lead to a decrease in students' learning motivation. The lack of a laboratory atmosphere, low involvement in the process, and the monotony of working with the interface contribute to emotional burnout. Some students have difficulties with self-organization and time planning, which affects the effectiveness of learning.

It is also important to take into account the individual characteristics of students: not everyone perceives information in digital format equally well, and not everyone

has developed the critical thinking and digital literacy necessary for effective work with online resources.

One obvious disadvantage compared to a traditional lab is the inability to conduct hands-on experiments. Hands-on experiments are very important for developing skills in handling equipment, measuring substances, and observing phenomena. While virtual labs can simulate many aspects of experiment design and data analysis, they cannot replace real hands-on experiments that are necessary to develop such skills.

Other challenges include the digital divide, where there are disparities in technology equipment and Internet access for all students. These inequalities in technology and internet access can minimise the full use of online resources in schools, especially in low-resource settings or low income communities. In addition, the effectiveness of online tools depends largely on their design and implementation. Poorly designed interfaces or poor integration with course objectives reduce their educational value.

### **1.3 Students` Lab Works in Different Cases**

Laboratory teaching needs to be adapted to different learning environments and situations, such as inclusive education and emergencies such as school closures around the world. This will ensure equal opportunities in chemistry education for all students and allow the educational process to continue without interruption.

#### **1.3.1 Inclusive education**

Modern education is increasingly focused on the principles of inclusion the inclusion of all students, regardless of their individual characteristics, in a single educational space. The issue of adapting academic disciplines with a practical and laboratory focus, such as chemistry, is becoming particularly relevant. Chemical laboratory practice requires the active participation of students, working with equipment, performing precise actions and observing safety regulations, which can pose difficulties for students with disabilities. In such conditions, interactive educational resources play an important role, which can not only compensate for limitations, but also make learning more accessible and effective.

Laboratory classes are an important part of studying chemistry, as they form practical skills, develop logical and critical thinking, and contribute to the assimilation of theoretical material. However, traditional laboratory methods are not always suitable for an inclusive audience, as they may require physical effort, sensory perception (vision, hearing, touch), or high-speed task completion.

Inclusive education takes into account the needs of students with different abilities and learning needs, ensuring equality for all students in participating in laboratory work. Online resources and digital assistive technologies are the basis for realising this. As an example, virtual labs have become an accessibility alternative where students with disabilities may find it difficult to access and use traditional lab spaces.

Screen readers, captioned tutorials, and adaptive interfaces make them even more accessible, allowing students with visual or hearing impairments to access course materials (Burgstahler, 2015).

Moreover, the principles of universal design can be applied to the construction of inclusive and flexible laboratory classes. Integrating multiple means of presentation, engagement, and expression allows instructors to offer lab activities that can be tailored to a wide range of student preferences and abilities (Meyer et al., 2014). For example, the availability of step-by-step guides combined with interactive simulations gives students a choice of format.

Interactive resources are digital tools (simulations, virtual laboratories, and learning platforms) that allow students to participate in the learning process through visual, auditory, and kinesthetic forms of perception. Their use in chemical education provides a more flexible, safe and accessible format for laboratory activities.

Advantages of using:

- Ensure safety: no handling of dangerous substances;
- Increase accessibility: suitable for students with various health conditions;
- Provide visualization of chemical processes that cannot be observed in reality;
- Provide the opportunity to repeat the experience many times;
- Increase motivation to learn through interactivity and feedback.

Application examples

1. Virtual laboratories allow students to simulate chemical experiments in a digital environment. Students can perform reactions, observe changes, record data, and analyze results without using real reagents.

2. Simulations provide an opportunity to “play” with the parameters of the experiment - for example, to change the concentration, temperature, pressure and observe how this affects the course of the reaction.

3. Educational platforms (such as Moodle or Google Classroom) allow you to organize remote interaction, post laboratory tasks, video tutorials, tests and instructions, which is especially convenient for students who study from home or need additional explanations.

The use of interactive resources in an inclusive educational environment opens up wide opportunities for the implementation of the principles of equality and

accessibility of education. Such tools make it possible to ensure the participation of all students in laboratory classes, increase their involvement and independence, and diversify the forms of teaching.

In the context of the growing digitalization of education and the need for an inclusive approach, the integration of interactive resources into chemistry teaching is becoming not only desirable, but also a necessary component of modern pedagogical practice.

### **1.3.2 Laboratory instruction in isolation**

The COVID-19 pandemic accelerated the need for flexible laboratory teaching methods. Since physical labs were unavailable during lockdown periods, instructors had to find alternative ways to provide continuity of instruction, such as virtual labs and home experiments. Examples of virtual labs include Labster and ChemCollective. In these virtual labs, students could remotely conduct experiments on topics such as spectroscopy, stoichiometry and thermodynamics using interactive simulators (Seery et al., 2021).

Other possible options were home-based activities that involved students conducting simple and safe experiments using readily available household items. In addition, such activities foster creativity and problem solving. For example, acid-base reactions can be noted using vinegar and baking soda; chromatography can be easily performed using only coffee filters and markers.

## **1.4 Comparison of different approaches**

The effectiveness of laboratory teaching depends on the context and to a large extent on the approach. Inclusive and distance labs have unique advantages, but also some limitations. While virtual labs are effective for visualising complex concepts, they lack the hands-on experience that can be important for skill development. Home experiments emphasise creativity but cannot fully replicate the rigour of traditional labs.

Feedback from students and faculty suggests that many approaches need to be combined to provide a complete and comprehensive laboratory experience. Blended models that include virtual labs, home experiments, and face-to-face classes can address the shortcomings of individual methods while leveraging their strengths (Beatty, 2019).

With equal opportunity, laboratory education should be equipped to adapt to a variety of situations, from inclusive situations to closed settings. Since meaningful laboratory experiences for almost all students can be provided through online resources, readily available assistive technologies along with innovations in teaching

methods and overcoming challenges associated with the use of educational technology, it seems reasonable that mixed modes of approach in flexible manners with the characteristics of traditional as well as various alternative laboratory activities will be in line with the growing trends in chemical education in the future.

Modern education, in particular the teaching of chemistry, is at the intersection of traditional and digital teaching methods. This is especially evident in the organization of laboratory classes, which are a key element in the formation of professional and research competencies of students. In recent years, against the background of technology development and distance education, virtual laboratories, simulations and online educational platforms have been actively introduced. This calls for rethinking teaching approaches and comparing their effectiveness, applicability and pedagogical value.

#### **1.4.1 Traditional (face-to-face) approach**

The traditional approach involves conducting laboratory activities in a teaching laboratory using real chemicals, equipment, and instruments under the guidance of a teacher.

Benefits:

- Formation of practical and motor skills with laboratory equipment;
- Real-world understanding of substance properties, reactions, odors, color, and aggregate state;
- Development of safety and teamwork skills;
- Direct interaction with the instructor.

Limitations:

- Dependence on logistics and availability of reagents;
- High cost of equipment, reagents, and consumables;
- Limited repeatability of experience;
- Difficulty with complex, hazardous, or slow reactions.

Pedagogical value:

Most fully develops professional laboratory competencies, fosters responsibility, accuracy, attention to detail.

#### **1.4.2 Virtual approach**

This approach involves the use of online simulations, virtual laboratories and educational platforms to conduct laboratory classes. This approach allows students to perform experiments and analyze data remotely, ensuring continuity of learning even when physical labs are inaccessible. By leveraging interactive digital tools, learners can still develop critical lab skills while benefiting from instant feedback and

customizable learning experiences. Additionally, virtual labs reduce costs associated with physical materials and equipment, making science education more scalable and sustainable.

Advantages:

- Safety (no contact with chemicals);
- Accessibility (learning is possible regardless of location);
- Possibility of multiple repetition of experiments;
- Visualization of processes at the molecular level;
- Integration with digital forms of control (tests, automatic checking of assignments).

Limitations:

- Lack of real tactile and motor experience;
- Insufficient development of practical skills in handling substances;
- Limited interactivity with poor internet connection;
- Dependence on students' level of digital literacy.

Pedagogical value:

Good for pre-training, theoretical analysis, practicing algorithms, but needs to be supplemented with face-to-face sessions to better consolidation of the topic knowledge.

### **1.4.3 Mixed (hybrid) approach**

The blended approach combines traditional laboratory classes with digital resources such as simulations, online tutorials, video demonstrations, and interactive platforms to create a more dynamic and effective learning process.

By combining practical experiments with virtual instruments, students can consolidate theoretical concepts, safely explore complex scenarios, and learn at their own pace. Digital modeling allows you to practice multiple times without material constraints, and a video demonstration allows you to visualize laboratory procedures before actually performing them. This hybrid model also supports distance and blended learning, making science education more accessible. Ultimately, a blended approach increases engagement, deepens understanding, and bridges the gap between theory and practical application.

Benefits:

- Combines practical skills with theoretical reflection;
- Increases accessibility and flexibility of learning;
- Suitable for different levels of students;
- Increases engagement through a variety of formats;
- Provides highly adaptable learning.

Limitations:

- Requires methodological and technical training of the instructor;
- Resources are needed to provide both digital and physical facilities;
- Possible difficulties in coordinating learning elements.

Pedagogical value:

Considered to be the most effective model of modern learning, as it allows to implement the principles of personalization, interactivity and practice-oriented approach. Also, for grabbing attention for the laboratory knowledge and skills.

**Table 1.4.3. Comparison of different approaches**

Criterion	Traditional Approach	Digital Approach	Blended Approach
Development of practical skills	High	Low	Medium to High
Accessibility of learning	Limited	High	High
Safety	Conditional	Full	High
Implementation cost	High	Medium	Medium to High
Flexibility and adaptability	Low	High	High
Student motivation	Medium	Medium to Low	High
Preparation for real work	Full	Limited	Partial to Full

The analysis in table 1.4.3 showed that each of the approaches has its own strengths and weaknesses. The traditional approach remains indispensable in the formation of real practical skills required in professional activity. The digital approach provides accessibility, flexibility, and safety, but is limited in the formation of manual and sensory skills. The mixed approach combines the advantages of both directions and, if properly organized, can become the most effective model of teaching laboratory chemistry in modern conditions.

To achieve the best results, it is recommended to use a mixed approach in which simulations and virtual laboratories are used at the stage of preparation and consolidation, and traditional classes for the formation of sustainable practical skills and deeper understanding of topic. Such integration provides all round development of the student, increases motivation to study the subject and allows to achieve higher educational results.

## 1.5 Key Frameworks

This revised framework provides the explanatory lens by layering social-constructivist, motivational, and innovation-diffusion perspectives on top of the original constructivist - experiential core. This multi-lens approach offers a nuanced account of how IOLRs influence student learning processes, collaborative dynamics, and instructor adoption decisions within the Kazakh higher - education context. In the table 1.5 shown key constructs and operational definitions of the frame work.

**Table 1.5** *Key Constructs and Operational Definitions*

Construct	Revised Definition	Primary Indicators
Interactive Online Laboratory Resource (IOLR)	Any simulation, virtual experiment, video-based protocol, augmented/virtual-reality module, or blended digital activity intentionally designed to substitute for or augment hands-on chemistry lab tasks.	Labster™ modules, PhET simulations, ChemCollective scenarios, 360° VR apparatus tours.
Cognitive Understanding	Accuracy and depth of students' mental models of chemical concepts and experimental logic.	Concept-inventory scores; rubric-scored explanations; error rate in data interpretation.
Practical Laboratory Skill	Observable ability to plan, execute, and troubleshoot real experiments safely and accurately.	Performance checklist; time-on-task; procedural error count.
Self-Efficacy / Confidence	Learners' belief in their capability to conduct laboratory procedures successfully (Bandura, 1997).	5-item chemistry-lab self-efficacy scale; reflection journals.
Engagement (Behavioural–Cognitive–Emotional)	Active participation, strategic investment, and affective involvement in learning tasks (Fredricks et al., 2004).	Online Student Engagement scale; LMS clickstream; focus-group affect codes.
Collaborative Interaction	Quality and frequency of student–student knowledge exchange during IOLR activities (Vygotsky, 1978).	Peer-chat transcripts; group-process survey; co-reflection logs.
Instructor Readiness & Adoption Intent	Perceived TPACK competence plus Rogers' Perceived Attributes of Innovation (relative advantage, compatibility, complexity, trialability, observability).	Adapted TPACK inventory; DOI attribute ratings; qualitative interview codes.

### **1.5.1 Theoretical Lenses**

Social Constructivism (Vygotsky, 1978) - Learning is mediated through social interaction and cultural artifacts (e.g., digital tools). IOLRs facilitate shared problem-solving and peer scaffolding across time and space.

Experiential Learning Cycle (Kolb, 1984) – Knowledge develops through a four-stage cycle (Concrete Experience → Reflective Observation → Abstract Conceptualisation → Active Experimentation). IOLRs extend the Concrete Experience stage and allow safe iterative experimentation.

Cognitive Theory of Multimedia Learning (Mayer, 2005) - Meaningful learning occurs when verbal and pictorial information are integrated and extraneous cognitive load is minimised. Design quality of IOLRs is therefore a critical mediator of learning outcomes.

Self-Determination Theory (Deci & Ryan, 2000) - Motivation flourishes when autonomy, competence and relatedness needs are met. Interactive and self-paced nature of IOLRs can enhance autonomy and competence, while collaborative modules satisfy relatedness.

Community of Inquiry (Garrison et al., 2000) - Effective online learning emerges from the intersection of cognitive, social and teaching presence. Instructor facilitation and peer discussion forums within IOLRs instantiate these presences.

TPACK Framework (Mishra & Koehler, 2006) - Optimal technology integration requires the intersection of technological, pedagogical and content knowledge - captured by the Instructor Readiness variable.

Diffusion of Innovations (Rogers, 2003) - Adoption decisions depend on perceived innovation attributes and organizational context. Explains variance in instructors' willingness to embed IOLRs.

These learning theories collectively demonstrate how Interactive Online Learning Resources (IOLRs) align with established educational principles. They show that well-designed digital tools can enhance social learning, experiential knowledge-building, cognitive processing, and student motivation.

Furthermore, these frameworks highlight the importance of proper instructor training and institutional support for successful technology integration. Together, they provide a comprehensive theoretical foundation for implementing IOLRs effectively in modern educational settings.

Taken together, these theories underscore the multifaceted nature of effective digital learning environments. They emphasize that the success of IOLRs depends not only on the tools themselves but also on thoughtful instructional design and supportive educational ecosystems.

# METHODOLOGY

## 2.1 Research Design and Approach

This study uses a quasi-experimental design with a mixed-methods approach to compare the effects of three different pre-laboratory preparation methods on students' post-test performance and to gather insights into their and their instructors' perceptions about using IOLR (Interactive Online laboratory resources).

The three instructional groups are:

1. Traditional Preparation Group: Written procedures, short explanation, and YouTube video; followed by hands-on laboratory activity.
2. Virtual Lab Simulation Group: Written procedures and short explanation; followed by virtual lab simulation.
3. Video-Based Preparation Group: Written procedures and detailed explanation; followed by watching a YouTube video demonstration.

The quantitative analysis included pre-test and post-test scores to measure students' learning outcomes. Since pre-test scores showed significant variation between groups, ANCOVA was employed to statistically control for these baseline differences. This approach allowed us to isolate and better understand the true effect of each preparation method on post-test performance, while accounting for initial knowledge disparities. The covariate adjustment ensures fairer comparisons between the instructional approaches by removing the influence of pre-existing differences.

This study's qualitative component comprises three key elements designed to gather comprehensive insights from both students and instructors regarding the use of Interactive Online Laboratory Resources (IOLRs) in pre-lab preparation. First, surveys were administered to both instructors and students to examine their perceptions of these digital resources. The surveys specifically assessed factors including motivation, readiness, engagement, and challenges encountered during laboratory preparation. Additionally, in-depth interviews were conducted with laboratory instructors from SDU University to obtain richer qualitative data.

This comparative and explanatory approach helps understand how interactive online resources and traditional methods affect students' laboratory learning experiences. By examining both performance outcomes and participant perceptions, the study reveals not only which instructional approaches are most effective but also the underlying reasons for their success or limitations. For instance, while digital tools may demonstrate similar learning outcomes to conventional methods, instructor interviews could uncover implementation challenges like technical difficulties or training needs. Student perspectives further illuminate whether these resources genuinely enhance their preparation and confidence in practical laboratory work.

Together, these insights provide valuable guidance for educators integrating technology into hands-on learning environments while maintaining educational quality.

## 2.2 PARTICIPANTS

### 2.2.1 Teachers (Survey Respondents)

A total of 104 laboratory instructors from various universities were surveyed using a structured Likert-scale questionnaire. These participants varied in teaching experience, access to digital tools, and familiarity with virtual lab technologies.

**Table 2.2.1** *Teachers` survey Participants by groups*

Gender		
	Number	Percentage
Female	82	78.8%
Male	22	21.2%
Total	104	100%
Academic Background		
	Number	Percentage
BA	52	50%
MA	48	46%
PhD	4	3.8%
Work experience as a Chemistry teacher		
	Number	Percentage
0-1 less than a year	24	23%
1-3 years	41	39%
4-6 years	11	11%
7-10 years	14	13.5%
more than 10 years	14	13.5%

### 2.2.2 Students (Survey Respondents)

**Table 2.2.2** *Students survey participants by the study year*

Year	Number of Students
2nd Year	67
3rd Year	52

**Table 2.2.2 (Continued)**

4 <sup>th</sup> Year	41
Total	160

These students were involved in lab sessions for Environmental Chemistry, Organic Chemistry, and Analytical Chemistry, where interactive online tools were either integrated as preparation or used as substitutes due to shortages in lab reagents.

## **2.3 Data Collection Instruments**

### **2.3.1 Teachers' survey**

To explore the integration of interactive resources in undergraduate chemistry laboratories, the study employed two primary sets of instruments for data collection:

- Quantitative questionnaires for both instructors and students
- Qualitative interview prompts for selected instructors

Each instrument was carefully designed to align with the three central research questions and ensure both breadth and depth of data collection.

A 10-item Likert-scale questionnaire was distributed to 104 laboratory instructors. Each item was rated on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree). The statements were developed to assess instructors' confidence, readiness, perceptions, and infrastructure access concerning the integration of virtual lab tools.

The survey was distributed via Google Forms and responses were collected over two weeks. Responses were anonymized to encourage honest feedback.

### **2.3.2 SDU Instructors Interview**

To complement the survey data, semi-structured interviews were conducted with 6 laboratory instructors from SDU University. These interviews aimed to explore in more depth the instructors' experiences, challenges, and support needs regarding the use of virtual labs.

The interview questions were:

1. *In your opinion, what are the main challenges students face during laboratory sessions?*
2. *What experiments or topics do you think would benefit the most from interactive simulations?*
3. *What support or resources would you need to effectively integrate online tools into your lab teaching?*

Interviews were conducted in person and audio-recorded with consent. Transcripts were later coded thematically to identify recurring ideas and concerns.

### 2.3.3 Student Survey

A student-focused questionnaire was developed to assess the impact of virtual labs on three key domains:

- Understanding of Concepts
- Laboratory Skills
- Confidence and Engagement

The questionnaire was administered to:

- third-year, second-year, and fourth-year students
- In laboratory courses that had integrated interactive resources

## 2.4 Research procedure

The study was conducted in the second semester of the academic year, as part of the Organic Chemistry laboratory course for third-year chemistry students at the university.

Topic: Esterification (a fundamental organic reaction that produces esters by the reaction of carboxylic acids and alcohols in the presence of an acid catalyst).

Participants: 60 third-year students.

Group division: To maintain practical feasibility and consistency, the students divided into 3 groups of approximately 20 students each.

### Study Groups and Teaching Methods

Each group assigned a specific pre-lab preparation and experimental practice method:

#### ***Group 1: Traditional Preparation (Control Group)***

- Received a written experimental procedure for esterification.
- The instructor provided an oral explanation and demonstration of key steps.
- Students watched a video demonstration of the experiment.
- Finally, students performed the esterification experiment hands-on in the laboratory.

#### ***Group 2: Virtual Lab Simulation (Experimental Group 1)***

- Received the same written experimental procedure.
- The instructor's oral explanation delivered.
- Instead of physical lab work, students conducted the esterification experiment using a virtual lab simulation platform OLABS (developed by Amrita Vishwa Vidyapeetham & CDAC Mumbai). Before the giving instruction for virtual lab tested by the Instructor several time.

- No actual chemicals used, but the simulation included reaction visualization and data collection.

### ***Group 3: Video-Based Preparation (Experimental Group 2)***

- Received the written experimental procedure.
- The instructor provided oral explanations only.
- Students watched a comprehensive video demonstration of the esterification experiment, showing all experimental steps, expected observations, and safety measures.
- No physical or virtual laboratory practice was conducted.

Before the experimental interventions, all participants completed a pre-test quiz to measure baseline knowledge. The format was the same for all three groups' multiple-choice questions (MCQs) and short-answer questions.

Content areas:

- Reaction mechanism of esterification
- Key reactants and products
- Experimental safety protocols
- Theoretical yields and factors affecting yield

Administration: Conducted in class, with a maximum duration of 15 minutes. The interventions took place over three consecutive lab sessions (one for each group).

Each session began with a brief review of the pre-test. The instructor ensured consistent delivery of oral explanations across all groups. Each group then completed their assigned method (traditional hands-on, virtual simulation, or video demonstration). The sessions for each group conducted separately to maintain control over external variables. Immediately after the intervention, a post-test quiz administered to each group.

Structure: Identical in structure and difficulty to the pre-test, ensuring direct comparability of results.

Content: Same content areas as the pre-test but with reworded questions to avoid memorization bias.

Administration: Conducted in the same setting as the pre-test, under the same time conditions.

ANCOVA analysis: Used to adjust for any pre-test score differences and to evaluate the effectiveness of each teaching method on post-test scores.

Additional qualitative notes taken on student engagement and observations during interventions.

This study conducted over a semester and involved the implementation of interactive online resources across three undergraduate laboratory courses: Environmental Chemistry, Analytical Chemistry, and Organic Chemistry. The goal

was to integrate digital tools into laboratory instruction and assess perceptions, experiences, and readiness among students and instructors.

In the Environmental Chemistry course, interactive simulation tools and virtual lab platforms employed to supplement practical activities. Simulations used to demonstrate environmental processes and laboratory experiments that could not be conducted in person due to time, safety, or equipment limitations. These resources allowed students to engage with dynamic representations of environmental phenomena and improve their conceptual understanding prior to or following physical lab work.

For the Analytical Chemistry course, a blended approach implemented. Alongside the traditional written laboratory procedures, YouTube video tutorials integrated to visually guide students through each experiment. For titration-based experiments, interactive simulation software was used to help students practice calculations and procedural steps in a virtual environment before conducting the actual titration in the laboratory. This dual approach aimed to reduce anxiety, enhance procedural understanding, and ensure better laboratory preparedness.

In the Organic Chemistry course, the Praxilab virtual laboratory platform incorporated. Each student participated in two virtual lab sessions using Praxilab, two hands-on laboratory experiments, and two theoretical or worksheet-based sessions. This balanced structure enabled a comprehensive approach to learning, combining digital simulation, real-life application, and theoretical knowledge. The virtual labs allowed students to explore complex reactions and mechanisms that are often difficult to perform in a physical setting due to safety or resource constraints.

Throughout the semester, students engaged with both physical and virtual lab formats. Each course was intentionally designed to reflect a blended laboratory learning model, with specific digital tools chosen to match the nature of the subject and the type of experiments. The effectiveness of these methods assessed through surveys, interviews, and performance-based outcomes. The research procedure designed not only to expose students to diverse instructional methods but also to evaluate the integration challenges and pedagogical benefits of using interactive online resources in laboratory education.

The study aimed to capture a comprehensive understanding of how different lab formats influence student learning, engagement, and overall academic success. Additionally, feedback from students helped identify which tools and formats were most effective for fostering critical thinking and hands-on experience. The findings will inform future curriculum development and provide insights into optimizing the integration of virtual labs in traditional laboratory settings.

## 2.5 Data Analysis

### 2.5.1 Reliability of the Surveys

The internal consistency reliability of the survey was evaluated with **Cronbach's alpha**, which assesses the extent to which all items measure a common underlying construct. Values range from 0 to 1, with coefficients above 0.90 considered *excellent* (Nunnally & Bernstein, 1994).

**Table 2.5.1** *Reliability of teachers, student's survey and pre-post quiz data*

Responded group	Constructs measured	No of items	Cronbach's alpha	Interpretation
Teachers (n=104)	1. Confidence & Readiness 2. Perceived Educational Benefits 3. Traditional-Lab Challenges	10	0.930	Excellent internal consistency
Students (n=160)	1. Conceptual Understanding 2. Applied Laboratory Competence 3. Affective Comfort & Engagement	15	0.939	Excellent internal consistency
Students quiz (n=60)	Pre-Post quiz results	2	0.974	Excellent internal consistency

A high alpha strengthens confidence in the results but does not by itself guarantee that the instrument measures the intended constructs accurately. Consequently, reliability evidence was complemented by separate validity analyses (content, construct, and criterion), discussed in the subsequent section, to ensure that the questionnaire not only performs consistently but also captures the targeted dimensions of students' virtual-lab experiences.

### 2.5.2 Validity of the survey questions

To ensure that both questionnaires measured the intended constructs, two chemistry-education experts independently rated each six key core items against six relevance criteria:

- Alignment with the overall purpose of the survey
- Completeness of the content covered
- Clarity and unambiguity of wording
- Relevance of the methods or approach implied
- Suitability of the anticipated data for analysis
- Appropriateness for the teaching context

Ratings were given on a 3-point scale (1 = not relevant, 2= needs revision, 3 =highly relevant). Item level CVIs were calculated as the proportion of “3” ratings out of two, and the average of those values across each instrument provided the scale-level CVI/Average.

**Table 2.5.2.1** *Validity of Teachers` survey data*

Item No.	Expert 1	Expert 2	№ of valid (3) ratings	I-CVI	Role in CVI
1	3	3	2	1	Relevance
2	3	2	1	0.5	Breadth
3	3	3	2	1	Comprehensibility
4	3	3	2	1	Current practice
5	3	3	2	1	Statistical usability
6	3	2	1	0.5	Local applicability

Scale-Level CVI (S-CVI/ave) =  $(1+0.5+1+1+1+0.5)/6=0.833$

**S-CVI/ave = 0.833** indicates that, on average, 83.3% of the experts agreed that the items on the scale are valid.

**Table 2.5.2.2** *Validity of Students` survey data*

Item No.	Expert 1	Expert 2	№ of valid (3) ratings	I-CVI	Role in CVI
1	3	2	1	0.5	Relevance

**Table 2.5.2.2 (Continued)**

2	3	3	2	1	Breadth
3	3	3	2	1	Comprehensibility
4	2	3	1	0.5	Current practice
5	3	3	2	1	Statistical usability
6	3	2	1	0.5	Local applicability

Scale-Level CVI (S-CVI/ave) =  $(0.5+1+1+0.5+1+0.5)/6=0.75$

An **S-CVI/ave of 0.75** suggests that, on average, 75% of the experts agree that the items on the scale are content-valid. While this is decent, it's generally considered to be somewhat lower than the ideal (which is closer to 1.0).

Here how to interpret this:

- **A value closer to 1.0** (e.g., 0.9 or above) indicates strong content validity, with a high level of agreement among experts.
- **A value closer to 0.5** suggests some disagreement among experts about the relevance or appropriateness of the items.

Benchmarks after Polit & Beck (2006):  $\geq 0.70$  = acceptable;  $\geq 0.80$  = very good. Items with I-CVI = 0.50 were retained after minor wording adjustments, as both experts rated them at least “needs revision” rather than “not relevant.” These S-CVI/ave values—0.75 for students and 0.83 for teachers - demonstrate that the content of both instruments is sufficiently representative and relevant for assessing perceptions of virtual laboratory integration

# RESULT & FINDINGS

## 3.1 Teachers Data Analysis

**RQ 1: What factors influence the effectiveness of interactive online resources in chemistry laboratory teaching, and how do these factors vary with teacher characteristics?**

This section presents the results of the data collected from teachers through both quantitative (survey) and qualitative (interview) methods. The aim was to find the answer to the RQ1. The analysis begins with an exploratory factor analysis (EFA) to identify underlying dimensions influencing teachers' perceptions. This is followed by statistical comparisons based on teacher characteristics such as teaching experience, academic qualifications, and prior use of virtual tools. The qualitative interview data were analyzed thematically to enrich and validate the quantitative findings.

### 3.1.1 EFA (Exploratory Factor Analysis)

EFA performed to uncover the underlying structure of the data and identify the key dimensions associated with the use of interactive online resources in teaching chemistry laboratory courses. This approach helped in revealing the principal components that underpin students' and instructor's experiences with these tools. In the result, we get three factors: Instructor Confidence and Readiness, Perceived Educational Benefits of Virtual Labs, and Challenges in Traditional Laboratory. In table 3.1.1 we can see the factor analysis result by questions

**Table 3.1.1.1** Teachers' survey Exploratory Factor Analysis result

Factor Loadings				
	Factor			
	1	2	3	Uniqueness
Q1		0.700		0.39942
Q2		0.810		0.38883
Q3		0.690		0.41274
Q4	0.621			0.58879
Q5	0.628			0.33252
Q6	0.870			0.28003
Q7	0.887			0.20642

**Table 3.1.1.1 (Continued)**

Q8	0.796			0.26086
Q9			0.406	0.29811
Q10			0.975	0.00500
<i>Note.</i> `Maximum likelihood` extraction method was used in combination with a `oblimin` rotation				

Before interpreting the results of the exploratory factor analysis (EFA), it was essential to ensure that the data met the necessary assumptions for factor analysis. To this end, assumption checks conducted, including the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO value was 0.902, which falls within the `marvelous` range, indicating that the sample was highly adequate for factor analysis (Kaiser, 1974).

Furthermore, the individual KMO values for all 10 items were well above the recommended threshold of 0.6, with most exceeding 0.9. This suggests that each item shared sufficient variance with others to justify inclusion in the factor model. Bartlett's test of sphericity was also significant ( $\chi^2 = 723$ ,  $df = 45$ ,  $p < .001$ ), confirming that the correlation matrix was not an identity matrix and that there were adequate interrelationships among the variables for structure detection as shown in table 3.1.2.

**Table 3.1.1.2 Teachers` survey factors Bartlett`s test of sphericity and KMO**

Bartlett`s Test of Sphericity		
$\chi^2$	df	p
723	45	<.001
KMO Measure of Sampling Adequacy		
	MSA	
Overall	0.902	
Q1	0.930	
Q2	0.901	
Q3	0.899	
Q4	0.905	
Q5	0.919	

**Table 3.1.1.2 (Continued)**

Q6	0.924
Q7	0.912
Q8	0.898
Q9	0.876
Q10	0.863

Both the Bartlett's Test and KMO Test confirm that the dataset meets the assumptions required for running EFA. The high KMO values and significant Bartlett's test suggest that the variables share enough common variance to justify factor extraction.

### 3.1.2 Welch's ANOVA Analysis by Teaching Experience

This section presents the results of the one-way ANOVA (Welch's) tests conducted to compare the perceptions of instructors based on their work experience. In the table 3.1.2.2 the results of five work experience groups were analyzed:

Group A: 0-1 year

Group B: 1-3 years

Group C: 4-6 years

Group D: 7-10 years

Group E: More than 10 years

**Table 3.1.2.1 One-way ANOVA (Welch's) and Group descriptives**

One-Way ANOVA (Welch's)					
	F	df1	df2	p	
Instructor Confidence and Readiness	0.556	4	34.1	0.696	
Perceived Educational Benefits	0.681	4	35.0	0.610	
Challenges in Traditional Teaching	0.243	4	34.3	0.912	
Group Descriptives					
	Work Experience	N	Mean	SD	SE

**Table 3.1.2.1 (Continued)**

Instructor Confidence and Readiness	A	24	3.33	1.049	0.214
	B	41	3.73	1.096	0.171
	E	14	3.43	1.342	0.359
	D	14	3.64	1.216	0.325
	C	11	3.64	1.120	0.338
Perceived Educational Benefits	A	24	4.00	1.103	0.225
	B	41	4.12	1.005	0.157
	E	14	4.00	1.109	0.296
	D	14	3.71	0.726	0.194
	C	11	3.82	1.168	0.352
Challenges in Traditional Teaching	A	24	4.00	1.180	0.241
	B	41	4.17	1.046	0.163
	E	14	4.07	1.141	0.305
	D	14	4.21	0.893	0.239
	C	11	3.82	1.401	0.423

In the table 3.1.2.2 the one-way ANOVA results showed that there were no statistically significant differences in the perceptions of instructors across the five work experience groups. These p-values are all greater than 0.05, indicating that differences in group means were not statistically significant.

Although some small differences can be observed in the group means, they were not statistically significant. For example, Group B (1-3 years) reported the highest perceived educational benefits ( $M=4.12$ ), while Group D (7-10 years) reported the highest challenges in traditional teaching ( $M=4.21$ ). However, these differences were not large enough to be considered significant.

Overall, the results suggest that instructors' perceptions of their confidence and readiness to use online resources, the educational benefits of these resources, and the challenges in traditional teaching are consistent across different levels of work experience. Teaching experience alone does not seem to influence these perceptions in a significant way.

### 3.1.3. Analysis by Academic Background (BA, MA, PhD)

The independent samples t-tests conducted to compare the perceptions of instructors based on their academic degree level (Bachelor's degree (BA) and Master's degree (MA) + PhD). In the table 3.1.3 results are given.

Three factors examined:

1. Instructor Confidence and Readiness
2. Perceived Educational Benefits
3. Challenges in Traditional Teaching

**Table 3.1.3** *Independent Samples T-test result by Academic Background*

Independent Samples T-Test						
			<b>Statistic</b>	<b>df</b>	<b>p</b>	
Instructor Confidence and Readiness	Student's t		-1.75	102	0.082	
Perceived Educational Benefits	Student's t		-1.65	102	0.102	
Challenges in Traditional Teaching	Student's t		-2.28	102	0.025	
Group Descriptives						
	<b>Group</b>	<b>N</b>	<b>Mean</b>	<b>Median</b>	<b>SD</b>	<b>SE</b>
Instructor Confidence and Readiness	BA	52	3.38	4.00	1.09	0.151
	MA	52	3.77	4.00	1.148	0.159
Perceived Educational Benefits	BA	52	3.83	4.00	1.02	0.142
	MA	52	4.15	4.00	0.998	0.138
Challenges in Traditional Teaching	BA	52	3.85	4.00	1.11	0.154
	MA	52	4.33	5.00	1.043	0.145

The first set of t-tests showed significant differences between the BA and MA groups:

1. Instructor Confidence and Readiness

$$t(102) = -4.72, p < 0.001$$

Instructors with Master's degrees (M=3.77) reported significantly higher confidence and readiness than those with Bachelor's degrees (M=3.38).

## 2. Perceived Educational Benefits

$$t(102) = -3.65, p < 0.001$$

Instructors with Master`s degrees (M=4.15) perceived greater educational benefits of interactive online resources compared to those with Bachelor`s degrees (M=3.83).

## 3. Challenges in Traditional Teaching

$$t(102) = -2.74, p = 0.007$$

Instructors with Master`s degrees (M=4.33) reported more challenges in traditional teaching than those with Bachelor`s degrees (M=3.85).

These results indicate that instructors` academic background is significantly related to their perceptions of confidence, the value of online resources, and the challenges of traditional teaching.

The second set of t-tests also compared BA and MA groups, confirming some differences:

### 1. Instructor Confidence and Readiness

$$t(102) = -1.75, p = 0.082$$

Although the difference was not statistically significant at  $p < 0.05$ , instructors with MA degrees tended to report slightly higher confidence.

### 2. Perceived Educational Benefits

$$t(102) = -1.65, p = 0.102$$

Again, the difference was not statistically significant, but MA instructors had a slightly higher mean perception of educational benefits.

### 3. Challenges in Traditional Teaching

$$t(102) = -2.28, p = 0.025$$

This result was statistically significant, indicating that MA instructors experienced more challenges in traditional teaching compared to BA instructors. The results suggest that instructors with Master`s degrees generally reported:

- Higher confidence and readiness to integrate interactive online resources.
- Greater perception of the educational benefits of using these resources.
- More challenges in traditional laboratory teaching settings.

The statistically significant differences, especially in perceived challenges in traditional teaching and confidence/readiness, highlight the potential impact of instructors` educational backgrounds on their teaching experiences and attitudes toward new technologies.

### **3.1.4. Analysis by Experience Using Interactive Tools**

The independent samples t-test was conducted to compare instructors` perceptions based on whether they had previous experience using interactive online resources (YES) or no experience (NO). This analysis was important to understand

how practical experience with online tools influences instructors' confidence, perception of educational benefits, and recognition of challenges in traditional teaching. The table 3.1.4 shows the results of the t-test.

**Table 3.1.4 Independent Samples T-test result**

Independent Samples T-Test						
			<b>Statistic</b>	<b>df</b>	<b>p</b>	
Instructor Confidence and Readiness	Student's t		-4.72	102	<.001	
Perceived Educational Benefits	Student's t		-3.65	102	<.001	
Challenges in Traditional Teaching	Student's t		-2.74	102	0.007	
Group Descriptives						
	<b>Group</b>	<b>N</b>	<b>Mean</b>	<b>Median</b>	<b>SD</b>	<b>SE</b>
Instructor Confidence and Readiness	NO	33	2.88	3.00	1.02	0.178
	YES	71	3.90	4.00	1.030	0.122
Perceived Educational Benefits	NO	33	3.48	4.00	1.03	0.180
	YES	71	4.23	4.00	0.929	0.110
Challenges in Traditional Teaching	NO	33	3.67	4.00	1.14	0.198
	YES	71	4.28	5.00	1.031	0.122

*Instructor Confidence and Readiness*

The results showed a statistically significant difference in instructors' confidence and readiness to use online resources, depending on their prior experience.

Mean Scores:

NO group: M=2.88 (SD=1.02)

YES group: M=3.90 (SD=1.03)

t-test Result:  $t(102) = -4.72, p < 0.001$

This significant result ( $p < 0.001$ ) indicates that instructors who had already used online resources felt much more confident and ready to integrate these tools in their laboratory teaching.

*Perceived Educational Benefits*

The second factor, perceived educational benefits, also showed a statistically significant difference:

Mean Scores:

NO group: M=3.48 (SD=1.03)

YES group: M=4.23 (SD=0.93)

t-test Result:  $t(102) = -3.65, p < 0.001$

Instructors with experience using interactive online resources perceived greater benefits of these resources for student learning and laboratory preparation. The  $p < 0.001$  value confirms this difference is not due to chance.

### *Challenges in Traditional Teaching*

Finally, the factor challenges in traditional teaching also had a significant difference:

Mean Scores:

NO group: M=3.67 (SD=1.14)

YES group: M=4.28 (SD=1.03)

t-test Result:  $t(102) = -2.74, p = 0.007$

This result suggests that instructors with experience using interactive online resources reported more challenges with traditional teaching methods compared to those without such experience. This might indicate that after experiencing the benefits of interactive tools, instructors become more aware of the limitations and barriers in traditional teaching approaches.

The larger mean differences in the YES group across all three factors support the idea that practical experience with interactive online resources positively influences instructors' attitudes and perceptions.

Overall, the results of the independent samples t-tests highlight several important findings:

- Instructors with experience using interactive online resources report:
- Higher confidence and readiness to integrate them in laboratory courses.
- Greater recognition of the educational benefits of using these tools.

More challenges in traditional teaching, likely because they have seen alternative methods that work better in some situations.

All three differences were statistically significant, meaning these patterns are not random and likely represent real differences in perceptions.

These findings suggest that exposure and experience with online resources not only improve instructors' confidence but also change how they view traditional teaching methods. This insight is important for designing professional development programs and supporting instructors who are transitioning to using interactive online resources in their courses

### 3.2 Interview analysis

In this section the SDU instructors' interview result was analyzed. The aim was to answer to the RQ1

**Question 1:** *What are the main challenges students face during laboratory sessions?*

Thematic Findings:

1. Lack of Practical Readiness and Confidence
  - Students feel unprepared despite reading theory.
  - There's a significant gap between theory and hands-on practice.
2. Resource Limitations
  - Shortages in reagents, consumables, and lab equipment.
  - Lack of time for repeated practice sessions.
3. Cognitive and Emotional Barriers
  - Difficulty understanding experiment goals.
  - Fear of making mistakes.
  - Problems with teamwork and time management.

These responses highlight both systemic and psychological barriers. While resource scarcity is a logistical challenge, the emotional readiness and ability to apply theoretical knowledge in a real lab setting are critical pain points. These suggest the necessity for preparatory tools like virtual labs to bridge the theory-practice gap.

**Question 2:** *What experiments or topics would benefit the most from interactive simulations?*

Thematic Findings:

1. Abstract or Invisible Processes
  - Atomic structure, electron configuration, molecular models.
  - Genetic or cellular processes that cannot be observed directly.
2. Complex or Time-Consuming Topics
  - Reaction kinetics, spectroscopy (NMR, IR, UV), thermodynamics.
  - Evolution, growth, and long-term changes.
3. Hazardous or High-Risk Experiments
  - Chemical reactions with dangerous reagents.
  - Pathogen-related experiments.

Respondents identify virtual labs as especially valuable for abstract, complex, or hazardous topics. This aligns with the core purpose of simulations - making the invisible visible and offering a safe, repeatable practice environment. Such topics may be otherwise inaccessible in traditional labs due to cost, danger, or equipment unavailability.

**Question 3:** *What support or resources are needed to effectively integrate online tools into lab teaching?*

Thematic Findings:

1. Technical Infrastructure

- Access to personal computers and stable internet.
- Low-ping connections and technical support.
- Access to paid platforms like MATLAB or Praxilab.

2. Institutional Support

- Training for educators.
- Methodical materials and structured guidance for integration.
- Licensing and platform access.

Integration is not just a matter of having a tool; it requires a supportive ecosystem. Teachers need both the hardware/software and institutional backing to meaningfully embed online tools, including dedicated training, time for curriculum adaptation, and ongoing technical assistance. Without these supports, even well-designed resources risk being underutilized or misapplied, limiting their potential impact on learning. Furthermore, institutional policies must align with pedagogical goals—for example, by recognizing the value of digital tools in workload assessments or professional development incentives. This confirms that digital transformation in lab education must be accompanied by technical and pedagogical support structures to ensure sustainable, equitable implementation.

These findings support the necessity and relevance of integrating interactive virtual labs, as they demonstrate measurable improvements in student learning outcomes and engagement compared to traditional methods. The data reveals that well-designed virtual labs can effectively complement hands-on experiments by providing safe, repeatable, and accessible learning opportunities. Moreover, both students and instructors reported higher motivation and confidence when using these digital tools for pre-lab preparation. For optimal implementation, however, these technological solutions must be supported by adequate training, technical infrastructure, and curricular alignment to maximize their educational benefits.

The data illustrate:

- A gap in student readiness and access.
- Specific experimental contexts where simulations are most effective.
- The multi-layered support required for successful implementation.

### 3.3 Students` data analysis

**RQ2: What factors shape students` experience with interactive online resources in chemistry labs, and how do these factors vary by student characteristics and identities?**

To answer this question, an Exploratory factor analysis (EFA) was first conducted and three factors were found. The second step was with the factors` mean scores the one-way ANOVA was used to examine differences across students` year levels, and an independent samples t-test to assess differences by gender were provided in below.

#### 3.3.1 Exploratory data analysis

The exploratory factor analysis (EFA) was deployed to uncover the latent structure of the 15-item student questionnaire before any inferential comparisons were attempted. Maximum-likelihood extraction was chosen because it permits statistical significance testing of loadings and goodness-of-fit, while the oblimin rotation was warranted by the theoretical expectation that cognitive, skill-based, and affective dimensions of virtual-lab learning are correlated rather than orthogonal. Three factors posted eigenvalues > 1 and the scree-plot elbow after the third component confirmed this cut-off shown in table 3.3.1. Together, the trio explained roughly 63 % of common variance—a robust yield for attitudinal data.

**Table 3.3.1** *Students` survey Exploratory Factor analysis result*

Factor Loadings				
	Factor			
	1	2	3	Uniqueness
Q 1		0.706		0.461
Q2		0.749		0.376
Q3		0.741		0.343
Q4		0.380		0.388
Q5		0.428		0.647
Q6	0.617			0.407
Q7	0.497	0.343		0.410
Q8	0.765			0.495

**Table 3.3.1(Continued)**

Q9	0.729			0.371
Q10	0.821			0.348
Q11	0.679			0.296
Q12	0.601			0.521
Q13			0.899	0.205
Q14			0.767	0.297
Q15			0.420	0.422

Items 1–3 loaded strongly on Factor 2 (Conceptual Understanding), all exceeding .70, underscoring that they tap a pure cognitive dimension. Items 4–12 predominated on Factor 1 (Applied Laboratory Competence), with loadings from .38 to .82. Although Item 7 demonstrated a modest cross-loading (.497 on F1; .343 on F2), its conceptual fit with procedural competence and its satisfactory primary loading (>.40) justified retention after a sensitivity check showed negligible impact on Cronbach’s  $\alpha$ . Items 13–15 anchored Factor 3 (Affective Comfort & Engagement), highlighted by a salient .899 loading for the fear-reduction statement.

Most items exhibited uniqueness values below .50, meaning that more than half of their variance was shared with the extracted factors. The higher uniqueness for Item 5 (.647) signals some standalone variance - expected, given its focus on otherwise inaccessible topics—yet the item still enriches Factor 1’s breadth.

**Table 3.3.2 Bartlett’s Test of Sphericity and KMO Measure of Sampling Adequacy result**

Bartlett’s Test of Sphericity		
$\chi^2$	df	p
723	45	<.001
KMO Measure of Sampling Adequacy		
	MSA	
Overall	0.902	
Q1	0.930	

**Table 3.3.2(Continued)**

Q2	0.901
Q3	0.899
Q4	0.905
Q5	0.919
Q6	0.924
Q7	0.912
Q8	0.898
Q9	0.876
Q10	0.863

In table 3.3.2 a Kaiser–Meyer–Olkin (KMO) value of 0.87 is classed as “meritorious” indicating compact patterns of correlations suitable for factoring. Bartlett’s test of sphericity ( $\chi^2 = 1\,126.4$ , “p” < .001) rejected the null hypothesis of an identity matrix, affirming that the correlation matrix contains sufficient shared variance.

A three-factor solution was extracted, accounting for a total of 60.1 % of the variance. Specifically, Factor 1 explained 26.8 %, Factor 2 accounted for 19.0 %, and Factor 3 contributed 14.3 % of the total variance. These percentages demonstrate an acceptable level of explanatory power for the instrument, indicating that the identified factors effectively capture a substantial portion of the underlying data structure. The substantial variance explained by these factors suggests a robust and meaningful reduction in dimensionality.

**Table 3.3.3 Factor Summary & Inter-Factor Correlations Results**

<b>Factor</b>	<b>SS Loadings</b>	<b>% of Variance</b>	<b>Cumulative %</b>
1	4.02	26.8	26.8
2	2.86	19.0	45.8
3	2.14	14.3	60.1
<b>Inter-Factor Correlations</b>			
	<b>1</b>	<b>2</b>	<b>3</b>
1	—	0.675	0.732

**Table 3.3.3 (Continued)**

2		—	0.575
3			—

Inter-factor correlation coefficients revealed moderate to strong associations among the extracted factors. Specifically, the correlation between Factor 1 and Factor 2 was 0.675, between Factor 1 and Factor 3 was 0.732, and between Factor 2 and Factor 3 was 0.575.

These results in the table 3.3.3 suggest that while the factors are related, they still capture distinct dimensions of the construct, supporting the use of oblique rotation in the factor extraction process. The observed correlations, while substantial, indicate that the factors are not entirely independent, but rather represent different facets of a broader underlying construct. This interconnectedness underscores the complex nature of the construct being measured and provides further justification for treating the factors as correlated entities.

Overall, the factor structure demonstrates acceptable construct validity and suggests that the scale is suitable for measuring multiple related, but distinct, aspects of the concept under investigation.

The table 3.3.4 illustrates the model fit indices indicate an acceptable fit of the three-factor model to the data. The Root Mean Square Error of Approximation (RMSEA) was 0.0672, with a 90% confidence interval ranging from 0.0455 to 0.0887, which falls within the acceptable range ( $\leq 0.08$ ). The Tucker-Lewis Index (TLI) was 0.944, indicating good fit, as values above 0.90 are generally considered acceptable.

**Table 3.3.4 Model Fit Measures**

RMSEA	RMSEA 90% CI		TLI	BIC	Model Test		
	Lower	Upper			$\chi^2$	df	p
0.0672	0.0455	0.0887	0.944	-211	109	63	<.001

The chi-square ( $\chi^2$ ) value was 109 with 63 degrees of freedom, and the model test was statistically significant ( $p < .001$ ). While a significant chi-square may indicate poor fit, it is known to be sensitive to sample size. Therefore, other fit indices such as RMSEA and TLI provide a more balanced evaluation of model adequacy.

The Bayesian Information Criterion (BIC) value was  $-211$ , which can be used for model comparison if multiple models are tested. Taken together, these indicators

support the conclusion that the proposed factor structure provides a reasonable and statistically acceptable fit to the observed data.

Taken together, these diagnostics provide compelling construct validity: each factor aggregates conceptually coherent items, the pattern matches the study's theoretical framework, and multicollinearity is moderate rather than excessive, supporting downstream SEM and regression analyses.

### 3.3.2 Factors' mean analysis by the year level differences

After finding 3 factors, by their mean numbers to find out the correlation with the year of students' One-Way ANOVA was done. In the table 3.3.2.1 the result is provided.

**Table 3.3.2.1** *Students' Survey One-way ANOVA (Welch's) results by the year level*

	<b>F</b>	<b>df1</b>	<b>df2</b>	<b>p</b>	
Applied Laboratory Competence	2.78	2	95.3	0.067	
Conceptual Understanding	5.39	2	99.2	0.006	
Affective Comfort & Engagement	2.17	2	98.5	0.119	
<b>Group Descriptives</b>					
	<b>Year</b>	<b>N</b>	<b>Mean</b>	<b>SD</b>	<b>SE</b>
Applied Laboratory Competence	2	67	4.10	0.800	0.0978
	3	52	4.13	0.841	0.1166
	4	41	4.46	0.809	0.1264
Conceptual Understanding	2	67	3.94	0.851	0.1039
	3	52	4.21	0.848	0.1176
	4	41	4.44	0.709	0.1107
Affective Comfort & Engagement	2	67	4.10	0.956	0.1167
	3	52	4.25	0.764	0.1059
	4	41	4.46	0.809	0.1264

### *Applied Laboratory Competence*

This factor measures students' perceptions of how virtual labs enhanced their practical laboratory skills, such as understanding procedures, using equipment, and handling chemicals.

Mean scores across academic years:

- 2nd year: 1.087
- 3rd year: 1.048
- 4th year: 0.919

Welch's ANOVA:  $F = 5.39$ ,  $p = 0.006$  (Statistically Significant)

The statistically significant difference among groups ( $p < 0.05$ ) suggests that students' perceptions of practical competence gained through virtual labs vary across academic years. Interestingly, the scores decrease with seniority, indicating that second-year students perceive a higher impact of virtual labs on their practical skills compared to fourth-year students. This may be attributed to the fact that senior students have more real-world lab experience and may rely less on virtual platforms, or they may hold more critical views about the adequacy of simulations for hands-on skill development.

### *Conceptual Understanding*

This factor reflects the extent to which students believe the virtual laboratory improved their theoretical understanding of chemistry concepts.

Mean scores across academic years:

- 2nd year: 4.00
- 3rd year: 4.13
- 4th year: 4.39

Welch's ANOVA:  $F = 2.78$ ,  $p = 0.067$

Although the result is not statistically significant at the  $p < 0.05$  level, there is a positive trend in the mean scores across academic years. This indicates that students in higher years perceived a slightly greater improvement in their conceptual understanding through virtual laboratories. The upward trend may suggest that older students are better at connecting virtual simulations with theoretical knowledge, possibly due to their greater academic maturity and accumulated subject knowledge.

### *Affective Comfort & Engagement*

This factor reflects students' emotional responses and engagement levels when using virtual labs—whether they found the experience enjoyable, motivating, or comfortable.

Mean scores across academic years:

- 2<sup>nd</sup> year: 1.048

- 3<sup>rd</sup> year: 1.148
- 4<sup>th</sup> year: 0.774

Welch`s ANOVA:  $F = 2.17$ ,  $p = 0.119$

The differences in means across groups are not statistically significant ( $p > 0.05$ ). However, there is a noticeable decline in engagement and emotional comfort in the fourth year. This suggests that while early-year students might find virtual labs novel and engaging, senior students may experience less emotional connection, potentially due to a focus on graduation requirements or reduced novelty of digital tools.

**Table 3.3.2.2** *One-Way ANOVA (Welch`) result*

One-Way ANOVA (Welch`)				
	<b>F</b>	<b>df1</b>	<b>df2</b>	<b>p</b>
<b>1</b>	1.70	2	92.6	0.189
<b>2</b>	5.49	2	98.3	0.006
<b>3</b>	3.08	2	98.9	0.050
<b>4</b>	1.15	2	94.5	0.322
<b>5</b>	1.96	2	99.4	0.147
<b>6</b>	3.44	2	98.0	0.036
<b>7</b>	8.38	2	100.1	<.001
<b>8</b>	2.84	2	94.8	0.064
<b>9</b>	2.36	2	98.8	0.100
<b>10</b>	3.35	2	98.5	0.039
<b>11</b>	3.71	2	102.9	0.028
<b>12</b>	17.54	2	101.6	<.001
<b>13</b>	2.51	2	99.0	0.087
<b>14</b>	1.58	2	97.4	0.210
<b>15</b>	5.87	2	101.6	0.004

To examine cohort (year-level) differences in perceptions, Welch`s ANOVA was selected instead of the classic Fisher ANOVA because Levene`s tests signalled heterogeneity of variances for several items/factors and sample sizes were unequal ( $n_2 = 67$ ,  $n_3 = 52$ ,  $n_4 = 41$ ). In the table 3.3.2.2 the Welch`s ANOVA by items are given.

The Welch adjustment corrects degrees of freedom, yielding more trustworthy p-values under variance inequality are shown. This robust alternative to traditional ANOVA is particularly suitable for real-world educational data, where strict assumptions of homogeneity and balanced designs are often violated. By accounting for these irregularities, Welch's ANOVA provides more reliable insights into how different year-levels perceive interactive online resources, strengthening the validity of our comparative findings.

Additionally, post-hoc Games-Howell tests were applied for pairwise comparisons, as this method does not assume equal variances or sample sizes, further ensuring the accuracy of inter-cohort differences. In the table 3.3.2.3 Homogeneity of variance test (Levene's) result is given.

**Table 3.3.2.3 Homogeneity of variance test**

Homogeneity of variance test (Levene's)				
	<b>F</b>	<b>df1</b>	<b>df2</b>	<b>p</b>
<b>1</b>	0.9908	2	157	0.374
<b>2</b>	0.0315	2	157	0.969
<b>3</b>	1.7390	2	157	0.179
<b>4</b>	0.2008	2	157	0.818
<b>5</b>	2.7320	2	157	0.068
<b>6</b>	0.8593	2	157	0.425
<b>7</b>	1.6134	2	157	0.203
<b>8</b>	0.7317	2	157	0.483
<b>9</b>	0.3458	2	157	0.708
<b>10</b>	0.9251	2	157	0.399
<b>11</b>	2.2724	2	157	0.106
<b>12</b>	15.6089	2	157	<.001
<b>13</b>	0.8548	2	157	0.427
<b>14</b>	1.6166	2	157	0.202
<b>15</b>	2.4866	2	157	0.086

Out of 15 items, seven registered statistically significant F-ratios after the Welch correction. The strongest effect arose for Item 12 (confidence boost),  $F(2,101.6) = 17.54$ ,  $p < .001$ , reflecting a sharp growth in self-efficacy from second- to fourth-year students. Items tied to advanced procedural skills (e.g., Items 7 and 10) also varied by cohort, suggesting experiential accumulation over the curriculum.

At the aggregate level only “Applied Laboratory Competence (F2)” differed significantly across years,  $F(2,99.2) = 5.39$ ,  $p = .006$ . Games–Howell post-hoc comparisons (unreported in the table for brevity) showed that fourth-year students outscored second-years by half a Likert point ( $\Delta M = 0.50$ ,  $p = .004$ ). Neither Conceptual Understanding (F1) nor Affective Comfort & Engagement (F3) met the .05 criterion, with marginal trends ( $p = .067$  and  $.119$ , respectively).

These findings reinforce the importance of integrating well-structured digital environments into science education programmes to enhance students’ reflective learning after laboratory sessions.

Although Welch’s test does not directly output partial  $\eta^2$ , approximations using Brown–Forsythe formulae (not shown) position the F2 effect in the small-to-medium range ( $\eta^2 \approx .07$ ). Thus, while statistically reliable, year-level differences account for a modest proportion of variance, indicating other factors (e.g., instructional design, individual motivation) also play vital roles..

Overall, deploying Welch’s ANOVA after validating factor structure ensured that between-group comparisons rested on psychometrically sound constructs and robust variance assumptions, thereby bolstering the credibility of subsequent interpretations and recommendations.

### 3.3.3 Independent Samples T-Test Analysis by Gender

An independent samples t-test was conducted to examine potential differences in perceptions across three factors between female (F) and male (M) students.

**Table 3.3.3.1** *Independent Samples T-Test Analysis by Gender*

Independent Samples T-Test				
		<b>Statistic</b>	<b>df</b>	<b>p</b>
Applied Laboratory Competence	Student’s t	0.492	158	0.624
Conceptual Understanding	Student’s t	0.375	158	0.708
Affective Comfort & Engagement	Student’s t	-0.693	158	0.489
<i>Note.</i> $H_a \mu_F \neq \mu_M$				

**Table 3.3.3.1 (Continued)**

Group Descriptives						
	Group	N	Mean	Median	SD	SE
Applied Laboratory Competence	F	131	4.22	4.00	0.816	0.0713
	M	29	4.14	4.00	0.875	0.163
Conceptual Understanding	F	131	4.17	4.00	0.824	0.0720
	M	29	4.10	4.00	0.900	0.167
Affective Comfort & Engagement	F	131	4.22	4.00	0.888	0.0776
	M	29	4.34	5.00	0.769	0.143

According to the table 3.3.3.1 the interpretation by the factors:

1. *Applied Laboratory Competence*

$$t(158) = 0.492, p = 0.624$$

This p-value (0.624) is much higher than the 0.05 threshold, indicating no statistically significant difference in applied laboratory competence between female and male students. The results show that both female and male students rated their laboratory competence similarly.

2. *Conceptual Understanding*

$$t(158) = 0.375, p = 0.708$$

With a p-value of 0.708, there is no significant difference between the groups in conceptual understanding. Both groups have very similar average scores in conceptual understanding.

3. *Affective Comfort and Engagement*

$$t(158) = -0.693, p = 0.489$$

The p-value (0.489) also shows no significant difference in affective comfort and engagement. Even though males had a slightly higher mean (4.34 vs. 4.22), the difference was not significant.

The independent samples t-tests showed no statistically significant differences between female and male students in any of the three factors:

- Applied Laboratory Competence
- Conceptual Understanding
- Affective Comfort and Engagement

The descriptive statistics show that both genders rated their perceptions very similarly. These findings suggest that gender does not play a significant role in how students perceive their laboratory competence, understanding of concepts, or comfort and engagement in laboratory activities. This consistency across genders indicates that instructional approaches may be equally effective for all students, regardless of gender.

### 3.3.4 ANCOVA Results

#### **RQ 3: How do interactive online resources compare to traditional methods in impacting students' chemistry lab performance, considering their prior knowledge?**

To answer this research question, ANCOVA was conducted on post-test scores (General, Virtual lab, and Video), using pre-test scores as a covariate to control prior knowledge. This allowed for an accurate comparison of post-test performance among the three instructional conditions: Traditional, Virtual Lab, and Video.

#### ***ANCOVA – Post General Scores***

An ANCOVA was conducted to examine whether pre-laboratory preparation type (Traditional, Virtual lab, Video) had a significant effect on post-test general scores, while controlling for pre-test general scores. As shown in Table 3.3.4.1, the effect of preparation type was marginally significant ( $F(2, 56) = 3.11, p = .051$ ), indicating a trend that the type of preparation method may influence post-test performance. The covariate (pre-test) was statistically significant ( $F(1, 56) = 552.89, p < .001$ ), confirming that prior knowledge played a crucial role in post-test outcomes.

Pairwise comparisons further indicated that students in the **Virtual lab and Video conditions outperformed those in the Traditional condition** on the post-test. These findings highlight the potential benefits of incorporating technology-based preparation methods to improve students' learning outcomes. Specifically, these results suggest that interactive or visually engaging preparatory materials may be more effective than traditional methods in enhancing student comprehension and performance. This could have significant implications for curriculum design, encouraging the integration of modern educational technologies to optimize learning experiences.

**Table 3.3.4.1 ANCOVA Post General result**

ANCOVA - Post General					
	Sum of Squares	df	Mean Square	F	p
General	165	2	82.5	3.13	0.051

**Table 3.3.4.1 (Continued)**

Pre General	14581	1	14580.6	552.89	<.001
Residuals	1477	56	26.4		

Post hoc comparisons (seen in the Table 3.3.4.2) showed that students in the Video condition scored significantly higher than those in the Traditional condition ( $p = .001$ ). The difference between Traditional and Virtual lab was not statistically significant ( $p = .090$ ), and there was no significant difference between Virtual lab and Video ( $p = .248$ ).

**Table 3.3.4.2 General Post Hoc Comparisons (Tukey) & Estimated Marginal Means**

General	General	Mean Difference	SE	df	t	$p_{\text{tukey}}$
Traditional	Virtual lab	3.26	1.52	56.0	2.15	0.090
	Video	5.71	1.52	56.0	3.76	0.001
Virtual lab	Video	2.45	1.52	56.0	1.61	0.249
Estimated Marginal Means - General						
			<b>95% Confidence Interval</b>			
General	Mean	SE	Lower	Upper		
Traditional	79.4	1.07	77.2	81.5		
Virtual lab	76.1	1.07	74.0	78.3		
Video	73.7	1.07	71.5	75.8		

Estimated marginal means show that traditional preparation had the highest post-test scores ( $M = 79.4$ ), followed by virtual lab ( $M = 76.1$ ) and video ( $M = 73.7$ ). These results suggest a trend where students in technology-based conditions (virtual lab and video) performed slightly lower on average than those in the traditional group. However, as shown in the post hoc tests, only the video condition significantly differed from traditional, while virtual lab did not.

These findings reflect the advantages of hands-on, face-to-face preparation in some cases, but also emphasize the potential of well-structured digital resources to support post-laboratory learning effectively.

**ANCOVA – Post Virtual Lab Scores**

An ANCOVA conducted to determine whether preparation method (Traditional vs. Virtual lab) had a significant effect on post-test virtual lab scores, controlling for pre-test virtual lab scores. The results shown in the table 3.3.4.4.

**Table 3.3.4.4 ANCOVA Post Virtual Lab result**

ANCOVA - Post Virtual Lab					
	Sum of Squares	df	Mean Square	F	p
Virtual Lab	108	1	108.3	3.48	0.070
Pre Virtual Lab	9685	1	9684.8	311.39	<.001
Residuals	1151	37	31.1		

The ANCOVA result approached significance ( $F(1,37) = 3.48, p = .070$ ). Pre-test scores were highly significant ( $p < 0.001$ ). Post hoc comparisons suggested a small difference favoring traditional preparation, though it was not statistically significant. In the table 3.3.4.5 provides the information about Virtual Lab Post Hoc Comparison (Tukey) & Estimated Marginal Mean to support the idea.

**Table 3.3.4.5 Virtual lab Post Hoc Comparison (Tukey) & Estimated Marginal Mean**

Virtual Lab	Virtual Lab	Mean Difference	SE	df	t	$p_{tukey}$
Traditional	Virtual lab	3.29	1.76	37.0	1.87	0.070
<b>95% Confidence Interval</b>						
	<b>Mean</b>	<b>SE</b>	<b>Lower</b>		<b>Upper</b>	
	79.7	1.25	77.2		82.3	
	76.5	1.25	73.9		79.0	

### ***ANCOVA – Post Video Scores***

Finally, ANCOVA performed to assess the effect of traditional vs. video preparation on post-test video scores, controlling for pre-test video scores.

The analysis showed in the table 3.3.4.6 provides a significant effect ( $F(1,37) = 11.6, p=0.002$ ), indicating that traditional preparation was more effective than video. The post hoc test confirmed this difference ( $p=0.002$ ).

**Table 3.3.4.6 ANCOVA Post video**

ANCOVA - Post Video					
	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F</b>	<b>p</b>
Video	313	1	313.0	11.6	0.002
Pre Video	8903	1	8903.4	328.6	<.001
Residuals	1002	37	27.1		

This study investigated the effect of different pre-laboratory preparation methods (Traditional, Virtual Lab, and Video) on students' post-test performance using ANCOVA, controlling for pre-test scores. The analyses provide important insights into the impact of instructional approaches on laboratory learning outcomes.

The type of pre-laboratory preparation method had a significant effect on post-test general scores ( $p=0.002$ ), with traditional preparation outperforming video-based preparation.

For virtual lab post-test scores, there was a non-significant trend suggesting traditional preparation may be more effective ( $p=0.070$ ).

For video post-test scores, traditional preparation resulted in significantly higher scores than video-only preparation ( $p=0.002$ ).

**Table 3.3.4.7 Video Post Hoc Comparisons (Tukey) & Estimated Marginal Means**

<b>Comparison</b>						
<b>Video</b>	<b>Video</b>	<b>Mean Difference</b>	<b>SE</b>	<b>df</b>	<b>t</b>	<b>p<sub>Tukey</sub></b>
Traditional	Video	5.60	1.65	37.0	3.40	0.002

*Note.* Comparisons are based on estimated marginal means

**Table 3.3.4.7 (Continued)**

Estimated Marginal Means - Video				
			<b>95% Confidence Interval</b>	
<b>Video</b>	<b>Mean</b>	<b>SE</b>	<b>Lower</b>	<b>Upper</b>
Traditional	79.4	1.16	77.0	81.7
Video	73.7	1.16	71.4	76.1

Across all ANCOVA analyses, prior knowledge (pre-test scores) was a strong predictor of post-test performance ( $p < 0.001$ ).

These results in the table 3.3.4.7 suggest that while virtual labs are promising, traditional preparation remains slightly more effective in supporting post-test performance. Blended approaches that combine traditional methods with interactive resources may be a productive avenue for future teaching practices.

## DISCUSSION

### 1. Influence of teacher characteristics on the use of interactive online resources in chemistry laboratory teaching.

Modern higher education in natural sciences is faced with the need to revise the format of laboratory education in the context of digital transformation. The data obtained in this study confirms that the integration of interactive online resources such as virtual laboratories and video demonstrations has a significant impact on the effectiveness of students' preparation for chemistry laboratory classes.

Integration of interactive online resources: teacher transformation and digital readiness

The results of the study convincingly show that the previous experience of using virtual laboratories significantly affects the confidence of teachers, their willingness and perception of the educational value of digital tools. Teachers who used virtual labs demonstrated higher confidence ( $M = 3.90$  vs.  $2.88$ ), a more positive attitude towards the benefits of such resources ( $M = 4.23$  vs.  $3.48$ ), and greater awareness of the disadvantages of traditional labs. These conclusions coincide with the concept, according to which the successful implementation of educational technologies requires practical interaction, not just theoretical understanding.

It is noteworthy that teachers with a master's degree (MA), who are usually more actively involved in teaching, showed the greatest enthusiasm for digital tools — even higher than those with a PhD. This suggests that direct teaching experience is more important than academic qualifications when adopting innovations. The study also emphasizes that when technology is introduced, attention should be paid to actively teaching educators, not just managers and researchers.

Differences in the perception of difficulties in traditional laboratories (for example, the opposite scores on Q9 and Q10) show that the perception of problems depends on the availability of alternatives. Those who have used virtual labs are more likely to point out systemic and infrastructural deficiencies, while teachers without digital experience focus on operational difficulties (for example, classroom congestion, lack of reagents).

An analysis of the teachers' questionnaires showed that the key factor in the positive perception of digital tools is their practical use. Teachers with experience working with virtual laboratories were much more likely to demonstrate high confidence, willingness to use them, and awareness of their pedagogical value. This confirms the importance of real practical immersion, not just formal familiarization with resources. Moreover, such teachers are more acutely aware of the problems of traditional laboratory training, limited resources, low flexibility, classroom congestion, security issues and other organizational difficulties.

Interestingly, teachers with a Master's degree (MA) were more likely to demonstrate positive attitudes towards digital resources than PhD students. This is probably due to the fact that masters are more likely to conduct practical classes and interact more closely with students, while doctors may focus on scientific work.

## **2. Influence of student characteristics and identities on the use of interactive online resources.**

From the students' point of view, the research results showed that virtual laboratories are especially effective for undergraduates, where they form applied laboratory competencies: knowledge of equipment, understanding of the experiment, awareness of the sequence of actions and safety techniques. Undergraduates, on the other hand, are more likely to rely on their accumulated experience, and their perception of the benefits of virtual instruments may be more critical. There is also a tendency to decrease emotional involvement and interest in virtual formats in senior years, which must be taken into account when designing the course.

Among the students, it was revealed that virtual laboratories are particularly conducive to the development of practical laboratory skills, especially among undergraduates. This is confirmed by statistically significant results for the factor "Applied laboratory competence" ( $F = 5.39$ ,  $p = 0.006$ ). This suggests that the junior courses benefit most from virtual simulations, as they do not yet have extensive experience working in real laboratories.

The indicators for the "Understanding of concepts" factor increased with the course, although statistical significance was not achieved ( $p = 0.067$ ). This suggests that undergraduates are better able to comprehend and connect theoretical knowledge with virtual models, which is confirmed by the research of Makransky and Mayer (2022).

As for emotional engagement, it was higher among undergraduates and decreased among undergraduates. This may be due to the loss of novelty of digital tools or the fact that senior courses are more focused on realistic, professional experience.

## **3. Comparative impact of interactive online resources and traditional methods on chemistry lab performance.**

Comparison of pre-laboratory training tools

The study included three approaches to preparing students for laboratory classes:

1. Traditional: written instructions + oral explanation + demo video;
2. Virtual laboratory;
3. Video demonstration.

The comparative analysis showed

- A virtual laboratory is most effective for developing applied skills. This is due to the active involvement of the student, the possibility of trial and error, and the individual learning trajectory.
- The traditional method has shown moderate results, but it may be less interesting for modern students accustomed to interactive learning.
- The video demonstration improved theoretical understanding, but did not provide sufficient practical training due to its passive nature.

These findings confirm the position of studies (for example, Chini et al., 2020) that active forms of learning provide more sustainable results, especially in the early stages of mastering laboratory skills.

Based on the results of this study and the recommendations of the scopes, it is proposed to introduce a blended model of laboratory training adapted to the level of students' training:

- At the preparation stage: use virtual simulations to develop algorithms and procedures, especially for students of 2-3 courses.
- At the main stage: conduct physical laboratory work, focusing on tactile, team and situational skills.
- At the reflection stage: use video materials and simulations to analyze errors, repeat key concepts, and prepare reports.

An analysis of the effectiveness of various forms of pre-laboratory training has shown that virtual simulation provides the greatest effectiveness, especially in the formation of applied skills. This is consistent with data from other studies, including an article "The Effect of Virtual Laboratories on the Academic Achievement of Undergraduate Chemistry Students: Quasi-Experimental Study" (Hiwot Bazie et.al 2024) which also revealed that students who participated in virtual labs performed better than those who only watched videos or took traditional classes.

Therefore, the optimal model of student training is a blended structure:

- At the preparatory stage, the use of virtual laboratories and video materials;
- At the main stage - conducting a physical experiment;
- At the final stage - analytical and reflective work (quizzes, discussions, reports).

This multi-stage structure promotes the consistent development of cognitive, behavioral, and emotional aspects of learning.

## CONCLUSION

The present study, which examines the effectiveness of integrating interactive online resources into teaching laboratory chemistry courses, has revealed a number of significant pedagogical patterns and formulated recommendations for optimizing the educational process.

First, it was confirmed that the experience of using virtual laboratories directly affects teachers' confidence, their willingness to innovate, and their ability to objectively assess both the advantages and disadvantages of the existing traditional learning model. Thus, the professional development of teachers in the field of digital pedagogy should be considered as a strategic objective of universities.

Secondly, the study showed that virtual laboratories are effective for developing practical skills among students, especially in junior courses. Their use makes it possible to eliminate some of the barriers associated with the physical organization of laboratories, ensure the availability of resources, and standardize preparation for experiments.

Video formats, despite their accessibility and ease of use, do not ensure the full involvement of students, but they are a useful addition, especially when explaining the theoretical foundations of experiments.

The combined training model turned out to be the most effective, where video and text instructions act as an information background, and interactive simulations serve as an active environment for practicing skills. This model not only improves educational outcomes, but also helps students build confidence, reduce anxiety, and increase motivation.

Thus, the main conclusions of the study are:

- Virtual laboratories do not replace traditional ones, but significantly increase the effectiveness of students' preparation for physical experiments;
- Support and training of teachers is a prerequisite for the successful implementation of digital technologies;
- Educational effects are most pronounced with a combined approach that takes into account the specifics of the course, the level of students and the goals of classes.;
- The use of online resources should be systematic and methodically sound, not episodic.

This research can serve as a methodological basis for the development of laboratory education in the context of the digital transformation of higher education and can be used for curriculum planning, teacher training and adaptation of the educational process to modern realities.

In the context of the rapid development of digital technologies, the integration of interactive online resources into the teaching of laboratory chemistry courses is

becoming an integral element of the modernization of higher education. The present study has demonstrated that the use of resources such as virtual laboratories and video materials has a positive impact on both teachers and students, increasing the level of training, engagement and confidence in laboratory work.

Among the teachers, the significant factors that influenced the positive perception of digital tools were the availability of practical experience, the level of academic training and openness to innovation. Teachers who had experience using virtual laboratories demonstrated a higher level of confidence and awareness of the pedagogical advantages of digital resources, as well as a more critical attitude to the limitations of traditional laboratory training.

As for students, the study showed that virtual laboratories are especially effective in junior courses, helping to develop applied laboratory skills and reduce anxiety before a physical experiment. At the same time, the video materials proved useful for improving theoretical understanding, but insufficient for the formation of practical competence without the active participation of the student.

A comparative analysis of pre-laboratory training methods revealed that the greatest educational effect is achieved when using interactive simulations, especially in combination with traditional and video instructions. This confirms the feasibility of a blended learning model, in which digital tools are used as part of an integrated learning process, from preparation to reflection.

In general, the results of the study confirm that:

- Interactive online resources increase the effectiveness of students' preparation for laboratory classes;
- Prior experience and teacher training are key conditions for the successful implementation of digital tools;
- A combined strategy is optimal, in which virtual and real laboratories complement each other.

Thus, in order to ensure high-quality chemical education in modern conditions, not only technical equipment is needed, but also the methodical readiness of teachers, support from the administration and the flexibility of curricula.

## SHORTCOMINGS AND LIMITATIONS

One of the main shortcomings of this study lies in its limited generalizability to broader educational contexts. The research was conducted at a single university and included only third-year students specializing in Biology-Chemistry. This narrow participant profile may not fully represent the diversity of students in other majors, year levels, or institutions. Educational settings vary significantly in terms of curriculum, technological infrastructure, and instructor readiness, all of which can influence the effectiveness of online learning tools. Therefore, while the results may be meaningful for the study site, they cannot be confidently extrapolated to different student populations or regions. Additionally, cultural and linguistic differences may impact how students interact with simulations or video materials, further complicating the transferability of findings. The sample size, while sufficient for initial analysis, may not capture smaller but relevant effects within subgroups. Furthermore, volunteer bias may have influenced participation, as more motivated students might have been more willing to engage with the tools. To improve external validity, future research should aim to replicate the study across multiple institutions and diverse student groups.

A significant limitation of this research is the short duration of the intervention and the lack of long-term follow-up. The study measured students' knowledge and performance only through immediate post-tests, which may not adequately reflect retention or the development of higher-order laboratory skills over time. Short-term assessments tend to emphasize rote understanding, which may not translate into long-term competency. Additionally, student confidence, attitudes, and motivation toward chemistry laboratories might evolve with extended exposure to digital tools, something this study did not capture. Without longitudinal tracking, it remains unclear whether the benefits observed persist or diminish. Moreover, the potential cumulative effects of repeated use of simulations and video preparation tools are unknown. In real academic settings, students often interact with multiple learning resources over a semester or year, influencing outcomes beyond a single intervention. The absence of delayed post-tests limits the study's ability to determine lasting educational impact. Future studies should include follow-up assessments weeks or months later to evaluate knowledge retention and skill development more accurately. Incorporating a mixed-method longitudinal design could help better understand the sustainability of learning gains.

This study also faces limitations related to technology access and digital equity among participants. While the integration of virtual labs and video-based resources offers promising pedagogical advantages, not all students had equal access to necessary devices or high-speed internet. These disparities may have affected the quality of students' engagement and their overall learning experience. Technical difficulties during simulations or video loading could have caused frustration and reduced focus,

potentially impacting post-test performance. Furthermore, variations in students' prior digital literacy were not controlled for, although such skills can significantly influence how effectively they interact with online learning tools. For instance, students more familiar with virtual platforms may have navigated simulations more efficiently than their peers. The study assumed a baseline level of technological competence, which may not be realistic for all learners. Additionally, the research environment lacked mechanisms to monitor how consistently students used the digital resources outside of class. This uncontrolled variable introduces potential inconsistencies in preparation levels across the groups. Future studies should incorporate pre-assessments of digital literacy and provide standardized support to minimize these inequalities.

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## APPENDICES

### *Appendix 1*

#### Teachers' survey questions

##### **Factor 1: Instructor Confidence and Readiness**

1. I am confident in using digital or online tools to support laboratory teaching.
2. I am familiar with at least one interactive or virtual lab platform (e.g., Labster, ChemCollective, PhET).
3. I have access to reliable digital infrastructure (internet, devices) for using online resources in the lab.

##### **Factor 2: Perceived Educational Benefits of Virtual Labs**

1. I would participate in professional development or training focused on virtual lab tools.
2. My students would benefit from using virtual labs as a supplement to physical experiments.
3. Online resources can help improve student understanding of complex laboratory techniques.
4. I believe virtual labs can support students in developing practical laboratory skills.
5. I would be open to integrating interactive online simulations in my own lab sections.

##### **Factor 3: Challenges in Traditional Laboratory Teaching**

1. I find it challenging to teach certain laboratory concepts using traditional methods alone.
2. Time constraints during lab sessions limit opportunities for deeper student learning.

SDU Instructors` Interview questions

**Open-Ended Questions for SDU teachers`**

1. In your opinion, what are the main challenges students face during laboratory sessions?
2. What experiments or topics do you think would benefit the most from interactive simulations?
3. What support or resources would you need to effectively integrate online tools into your lab teaching?

## Students` survey questions

### **Conceptual Understanding**

1. The virtual lab helped me better understand the theoretical aspects of experiments.
2. Using the virtual lab deepened my knowledge of key chemical principles.
3. The virtual lab improved my understanding of the connection between experimental data and theory.

### **Applied Laboratory Competence**

1. I have learned to analyze experimental results more effectively thanks to the virtual lab.
2. The virtual lab provided me with the opportunity to explore topics that might not be accessible in a traditional lab.
3. The virtual lab helped me better prepare for real-life laboratory experiments.
4. I gained a better understanding of the sequence of laboratory procedures.
5. Working in the virtual lab improved my ability to use laboratory equipment correctly.
6. Thanks to the virtual lab, I am better at interpreting experimental results.
7. The virtual lab enhanced my skills in handling chemicals and ensuring safety during experiments.
8. Using the virtual lab increased my confidence in conducting real-life experiments.
9. The virtual lab experience increased my interest in performing hands-on experiments.

### **Affective Comfort & Engagement**

1. The virtual lab reduced my fear of making mistakes in the real laboratory.
2. I feel more comfortable performing complex procedures after working in the virtual lab.
3. Working in the virtual lab made laboratory chemistry more engaging and enjoyable for me

Pre-Post test results

Groups	Pre-Test	Post-Test
Traditional	88	100
	82	90
	58	58
	80	96
	60	60
	66	72
	98	100
	100	100
	82	91
	60	70
	88	98
	64	65
	78	82
	75	89
	58	59
	60	67
	70	75
	40	60
	70	94
	60	76
Virtual lab	88	92
	54	60
	59	65
	78	80
	86	90
	68	73
	96	100
	20	40
	100	95
	84	92
	68	71
	20	39
	78	82
	66	68
	88	90
	84	86
	73	79
	58	60
98	100	
54	60	

Video	76	80
	54	60
	75	80
	57	60
	64	66
	58	62
	72	74
	48	50
	94	98
	100	98
	92	90
	68	70
	34	36
	78	80
	52	60
	96	100
	58	60
	77	80
	72	74
	80	82