



Assessing the accessibility of virtual chemistry laboratories for school students with special educational needs

Assel Absattarova

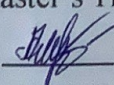
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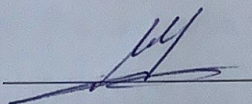
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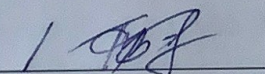
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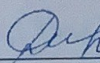
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LIST OF ABBREVIATIONS

ADHD – Attention-Deficit/Hyperactivity Disorder

AR – Augmented Reality

DD – Developmental Delays

HD – Hearing Disabilities

LD – Specific Learning Difficulties

PD – Physical Disabilities

RQ – Research Questions

SEN – Special Educational Needs

SL – Speech & Language

VL – Virtual Laboratory

VCL – Virtual Chemistry Laboratory

VD – Visual Disabilities

VR – Vitrual Reality

ABSTRACT

Students with special educational needs (SEN) often face limitations in studying natural science subjects, including chemistry, where laboratory practice must be constantly conducted to consolidate theoretical knowledge. The main purpose of this study was to study the effectiveness of the use of virtual chemical laboratories (VCL) as an educational tool for this category of students.

The study examined the following issues, such as how a student SEN perceives the virtual environment, what difficulties they face during work, and how the VCL affects their academic performance. The hypothesis is that a virtual chemistry laboratory needs to remove laboratory barriers from students with SEN, as well as help improve their academic performance. The research methodology is based on mixed methods of analysis: quantitative (pre- and post-test) and qualitative (structured interview and observation). The study involved 17 students with different categories of inclusion, enrolled in grades 6-9. The results of the data confirmed the positive impact of the virtual laboratory (VL) on students with SEN. Many students have recorded an increase in test scores. The qualitative analysis data confirms the quantitative results. The scientific novelty of this study lies in the simultaneous coverage of several inclusive groups, and the results of the study can serve as a basis for further research in this area.

Key words: *virtual chemistry laboratory, inclusive education, students with special educational needs, accessibility, education tools, chemistry education.*

АҢДАТПА

Ерекше білім беру қажеттіліктері бар оқушылар (ЕБҚ) жаратылыстану пәндерін, соның ішінде химияны оқуда жиі шектеулерге тап болады, мұнда теориялық білімді бекіту үшін зертханалық сабақтар үнемі жүргізілуі керек. Бұл зерттеудің негізгі мақсаты виртуалды химия зертханаларын (ВХЗ) студенттердің осы санаты үшін білім беру құралы ретінде пайдалану тиімділігін зерттеу болды.

Зерттеу барысында ЕБҚ бар оқушыларды виртуалды ортаны қалай қабылдайтыны, жұмыс кезінде қандай қиындықтарға тап болатыны және ВХЗ оның жұмысына қалай әсер ететіні сияқты келесі сұрақтар қарастырылды. Гипотеза бойынша, виртуалды химия зертханасы мүмкіндігі шектеулі оқушыларда пайда болатын зертханалық кедергілерді жоюы керек, сонымен қатар олардың үлгерімін жақсартуға көмектеседі. Зерттеу әдістемесі аралас талдау әдістеріне негізделген: сандық (тестілеуге дейін және кейін) және сапалық (құрылымдық сұхбат және бақылау). Зерттеуге әртүрлі инклюзия санаттары бар 6-9 сынып оқушыларының 17-сі қатысты. Деректерді талдау нәтижелері виртуалды зертхананың мүмкіндігі шектеулі оқушыларға оң әсерін растады. Көптеген оқушылар тестілеу нәтижелерінің артқанын атап өтті. Сапалық талдау деректері сандық нәтижелерді растайды. Бұл зерттеудің ғылыми жаңалығы бірнеше инклюзивті топтарды бір уақытта қамту болып табылады және зерттеу нәтижелері осы саладағы қосымша зерттеулерге негіз бола алады.

Түйін сөздер: виртуалды химия зертханасы, инклюзивті білім беру, ерекше білім беру қажеттіліктері бар оқушылар, қолжетімділік, оқу құралдары, химиялық білім беру.

АБСТРАКТ

Учащиеся с особыми образовательными потребностями (ООП) часто сталкиваются с ограничениями при изучении естественнонаучных предметов, включая химию, где необходимо постоянно проводить лабораторные занятия для закрепления теоретических знаний. Основной целью данного исследования было изучение эффективности использования виртуальных химических лабораторий (ВХЛ) в качестве образовательного инструмента для данной категории студентов.

В ходе исследования были рассмотрены следующие вопросы, такие как то, как студент с ООП воспринимает виртуальную среду, с какими трудностями он сталкивается во время работы и как ВХЛ влияет на его успеваемость. Гипотеза заключается в том, что виртуальная химическая лаборатория должна устранить лабораторные барьеры у учеников с ООП, а также помочь улучшить их успеваемость. Методология исследования основана на смешанных методах анализа: количественном (до и после тестирования) и качественном (структурированное интервью и наблюдение). В исследовании приняли участие 17 учащихся 6-9 классов с различными категориями инклюзии. Результаты анализа данных подтвердили положительное влияние виртуальной лаборатории (ВЛ) на учащихся с ООП. Многие учащиеся отметили увеличение результатов тестирования. Данные качественного анализа подтверждают количественные результаты. Научная новизна данного исследования заключается в одновременном охвате нескольких инклюзивных групп, и результаты исследования могут послужить основой для дальнейших исследований в этой области.

Ключевые слова: виртуальная химическая лаборатория, инклюзивное образование, учащиеся с особыми образовательными потребностями, доступность, инструменты обучения, химическое образование.

INTRODUCTION

Background of the Study

In the modern education system, a virtual chemical laboratory is a powerful tool for conducting laboratory classes in a safe environment. VCL has countless advantages, including cost-effectiveness, risk reduction, and a safe environment. However, their accessibility to students with SEN has not been evaluated globally (Alhashem et al., 2023).

The authors of Duarte & Butz (2001) note in their works that the main purpose of VLs is to create conditions as close as possible to a real electrical laboratory, and to provide users with the opportunity to learn the principles of working with devices and circuits. In addition, it can function both on a physical medium and online, which makes it a convenient tool for distance learning in engineering disciplines. Based on the material studied, several key tasks were formulated in this study:

1. In practice, evaluate the effectiveness of using a VCL as a tool to improve academic performance among students with SEN through a comparative analysis of test results.
2. Identify and classify technological and cognitive barriers among students with SEN in the process of interacting with the digital educational environment.
3. To investigate the subjective perception of the educational process by students with SEN, paying special attention to the chemical experience, emotional comfort, motivation and engagement.

Research Problem

According to Liu et al. (2022), the platform will be accessible to students with SEN with a logical and accurate visual design, intuitive navigation and adaptive functions. The accessibility of VCL is essential to ensure that all students can have equal access to learning without physical or cognitive limitations.

To solve these problems, Elfakki et al. (2023) developed and tested a three-dimensional VL designed for students with disabilities. Their study confirmed that the use of 3D technology promotes the development of cognitive skills, especially in the

study of physical disciplines. At the same time, the creation of inclusive VLs requires considering the specifics of various subject areas, as well as adapting to the needs of students with different individual characteristics, level of training, abilities and learning styles. This is especially important for students who use different ways of perceiving information (visual, auditory, kinesthetic), have different cognitive abilities, as well as for people with disabilities.

A few studies are devoted to studying the impact of VLs on various categories of students, including those with visual impairments and other disabilities. For example, Thompson et al. (2022) analyzed the effectiveness of inclusive VLs and found that participation in laboratory experiments contributes not only to improving the level of knowledge, but also to strengthening students' self-confidence. Today, students with musculoskeletal disorders face serious difficulties in mastering practical courses. In many cases, students who cannot use their hands can only watch their classmates perform laboratory work, which does not ensure a full-fledged educational process.

Significance of the Study

People with limited educational needs, representatives of different cultures and with various forms of disability study in an inclusive educational environment where they develop a sense of belonging, mutual respect and inclusion in society (Hodkinson et al., 2010).

Many educational institutions face the same gaps when working in a laboratory setting. These include the lack of organization for conducting laboratory classes, the need for qualified personnel, and the high cost of equipment. These factors can become barriers and hinder the acquisition of high-quality laboratory experience, which is important for students with disabilities. The development of digital technologies opens new opportunities to overcome these limitations. VLs allow students to conduct experiments at a convenient time and place, reducing financial costs and increasing the flexibility of the educational process. However, most of the existing solutions do not consider the needs of people with disabilities, which creates additional barriers to learning.

The study of inclusive VLs is becoming especially relevant in the context of the development of the principles of accessible and equitable education. The development of adaptive interfaces, the use of multimedia tools and the provision of interactive interaction can significantly improve the effectiveness of chemistry education for all categories of students.

Purpose

The authors of Duarte & Butz (2001) note in their works that the main purpose of VLs is to create conditions as close as possible to a real electrical laboratory, and to provide users with the opportunity

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The main purpose of this study is to conduct a training session with students with SEN using a VL, as well as to assess its impact on student academic performance and the level of convenience of this educational platform.

Research Questions

Thanks to the collected materials and clearly formulated goals, the following questions arise in this research work:

1. To what extent does the introduction of VCLs into the educational process affect the academic progress of students with special educational needs?

2. What cognitive and technical barriers do students with various forms of impairment encounter when using VCL?

3. How do students with SEN assess their chemical experience and emotional comfort when working in a virtual chemical environment?

Hypothesis

The integration of an adapted Virtual Chemistry Laboratory (VCL) significantly improves academic performance and increases emotional well-being (self-efficacy) among students with special educational needs by mitigating technical and cognitive barriers.

Research Contribution

Students with SEN are in many cases unable to actively participate in laboratory activities due to physical and cognitive limitations. This problem can be solved by replacing the traditional laboratory with the VCL. VCL provides various accessibility features such as visual and audio accompaniments, navigation, and an easy and logical interface. This means that the VHL is much more adaptable than traditional laboratories. We have demonstrated that an adapted virtual laboratory is an effective solution for overcoming significant learning barriers, thereby establishing a solid foundation for future inclusive education research. Moving forward, applying this methodology to more homogeneous groups, such as focusing on specific nosologies, will allow for greater statistical precision, more detailed interface customization, and the identification of subtle, disability-specific barriers.

LITERATURE REVIEW

2.1 Concept and Development of Virtual Chemical Laboratories

2.1.1 The Role of Laboratory Work in Chemical Education

The theoretical part should always be supported with practical tasks to gain effective knowledge of chemistry. Chemistry teachers believe that laboratory classes bring many educational benefits. Chemical laboratories are a unique environment where students work together in small groups to study chemical phenomena. Since chemistry is a science that is based on conducting experiments in laboratories, it is necessary to pay more attention to the practical part than to the theory. In addition, laboratory work is needed to increase engagement, develop interest, a positive attitude towards the subject, creativity and the ability to solve scientific problems, as well as to improve students' understanding of scientific concepts. There are many studies on chemistry teaching that suggest that students' laboratory experience needs to be improved, but despite these teaching methods, the student's academic performance is low. The main problem is the emotional aspects of learning, such as anxiety during the laboratory part (Kurbanoglu & Akin, 2010).

In his works, Ural (2016) emphasized the importance of the practical part of natural science subjects, when students in chemistry lessons actively participate in laboratory parts and conduct research to obtain new information, they increase confidence in their work. In other words, science lessons should be conducted in the format of a research method, replacing experiments in the style of “cookbooks”. The more laboratory work in chemistry, the less anxiety students have, and thus they improve their skills in conducting laboratory work. One of the problems of natural science subjects is the use of traditional methods such as lecturing. Usually, many teachers avoid the laboratory part of natural science subjects. This situation is typical not only for chemistry, but also for other scientific disciplines. As the author recommends, all teachers should improve their skills every year and should introduce more practical parts, but for this it is necessary to introduce more laboratory hours into the curriculum. Thanks to this recommendation, students can avoid abstract

comprehension in a natural science subject, and they can also apply their knowledge in everyday life.

The authors of Hofstein and Lunetta (2004) examined the impact of traditional research curricula based on research laboratory work in students. As a result, they concluded that research laboratory work is an important aspect for developing students' theory discussion skills. The performance of research laboratory work demonstrated the greatest results on the knowledge of the subject than the work carried out in traditional conditions. This shows that to understand chemistry; it is necessary to strengthen the laboratory part of the training program.

2.1.2 Functions of the Virtual Educational Environment

Thanks to adaptive functions, virtual environments offer users personalized learning, where work performance and grades are adjusted depending on individual student performance. The adaptive feature ensures that each student can receive training with their own unique needs. This in turn increases students' engagement and increases their abstract understanding. Virtual environment analytics allows you to monitor the student's progress and identify areas where additional teacher support is needed.

Integrated educational content management involves combining all subject-related activities, materials, and communication into one single connected platform. This type of approach simplifies the administrative part of the process for teachers and improves the quality of training.

Effective interaction and communication are important parts of successful learning. The virtual environment provides an opportunity to improve communication skills by blogging through functions such as instant messaging, discussion meetings, and collaboration. The communication environment always provides a greater sense that an individual is a part of society, as well as increasing mutual learning, increasing overall student engagement.

When performing chemical experiments, data is always generated that must necessarily be processed using mathematical calculations. Experiments that were

performed in a virtual environment also provide data, and based on this data, students draw some kind of conclusion on the topic. The analysis of the results plays a huge role here, and this, in turn, increases the practical experience and logical thinking of the student.

Inclusive assessment methods in a virtual environment target the different needs, experiences, and learning styles of all students. This link ensures that the assessment is fair, equitable and accurate. Virtual environments target various assessment methods such as online quizzes, interactive assignments, audience assessment, and project-based assessments to demonstrate skills and knowledge. Inclusive assessment, in turn, offers the opportunity for success for all students, regardless of their preferences or opportunities (Bezeri, 2025).

2.1.3 Technological Levels and Pedagogical Conditions of the Virtual Educational Environment

In a virtual learning environment, the most important process for conducting a lesson is full or partial immersion (immersion) in VR. Based on the Motejlek & Alpay taxonomy (2019), virtual environments are classified according to the level of immersiveness and the type of interaction between the user and the object. There are three levels of immersion that can make it possible to overcome barriers to learning.:

1. Non-immersive virtual environments (2D simulations). This is the most common type of VR. The work takes place through the input device and the standard monitor. From the perspective of inclusion, such technologies have a high accessibility potential.

2. Augmented Reality (AR). In this digital environment, AR overlays its digital objects onto the real physical environment. For education, AR technologies are of high value in terms of abstract concepts.

3. Fully immersive VR. This level provides for the consumption of special helmets (HMDs) and controllers that completely isolate the student from the real world. According to the authors, although this method may increase involvement, it may not be available for children with epilepsy and for children with severe forms of

musculoskeletal disorders. However, it is possible to solve these barriers with the help of additional assistants (a gaze control system).

An important classification parameter of the Motejlek & Alpay taxonomy (2019) is the concept of “degree of freedom”. This degree defines exactly how students can work freely in the laboratory space. The advantages of VR are justified by the fact that it favors immersive learning, teaching through simulations, as well as gamification processes. This structure can provide a high level of practical experience. Currently, there is an improved version of the virtual environment with a helmet, where students can build a hydrocarbon molecule with their hands, get a tactile educational connection using special gloves with built-in sensors. The developed virtual environment is called the multisensory VR Classroom (VRMC). User feedback has shown that VRMC represents a new generation of VR that supports full immersion in the study of molecular organic chemistry through interaction with tactile feedback. The digital tool demonstrates the potential to overcome scientific concepts that arise from the traditional teaching method (Edwards et al., 2019).

The virtual environment is highly immersive due to its high-quality schedule and the ability to fully immerse the user in learning, allowing them to study complex natural science disciplines. There is an immersive kind of VR where a person feels like a part of the ongoing process. According to the statistics of the analyzed experimental studies, immersive virtual reality (I-VR) demonstrated high rates of material assimilation. This tool is a promising pedagogical teaching method that can improve the effectiveness of learning, especially in areas where complex models or connection structures need to be visualized (Hamilton et al., 2021).

In a virtual environment, users can perform experiments, observe the results, and repeat actions several times, as if they were performing these physical activities in a real laboratory. Virtual labs are based on advanced computer programming and virtual environment simulation software. This software allows users to perform chemical reactions, mix chemicals, change concentrations, and heat all this in a digital space (Nakhleh & Krajcik, 1994).

According to the principles of universal design for learning (UDL), VL provides a variety of perception methods. VCL increases attention to learning and also promotes more inclusive digital learning. This virtual environment can hold students' attention through visual design (interactive, text, video), while maintaining high concentration throughout the entire course (Girmay et al., 2026). Virtual environments transform the educational system by providing innovative teaching tools and resources. Teachers play an important role in the effective use of virtual learning environments. Teachers should integrate innovative technologies into their teaching practices and adapt their roles to the demands of the digital environment. They create interesting and accessible learning materials and provide a guarantee for improving academic performance in the subject. This includes the development of multimedia content, online learning, and the creation of interactive projects. As a result, virtual environments make it easier for teachers to implement scientific concepts that cannot be implemented using traditional methods. Thus, teachers who have implemented digital technologies in teaching can satisfy students' different preferences (Anderson, 2008).

2.1.4 History of the Development of Virtual Chemical Laboratories

VCL is a platform where students can freely move from one place to another, use different reagents, and conduct chemical experiments in a chemical laboratory. In 2004 d'Ham (2004) presented the first VL for distance learning, where students could enter experimental data using an interface, and then the experiment was carried out by a bot. There were other versions of the chemistry laboratory, such as the periodic table, where students could organize groups and communicate with each other using different avatars, thereby studying the properties of an element (Shudayfat et al., 2012).

The first virtual labs were seen as new tools with great potential, but their use was limited to computer-aided learning in educational institutions. They were additional tools rather than the main components of science education, which in the old-fashioned way was built around physical laboratory work. However, with the development of technology, VCLs have begun to provide more complex chemical concepts and realistic models. Over time, teachers and educational institutions realized

the potential of virtual labs to improve students' abstract understanding, which increased student participation in the learning process. In parallel with the advent of online learning, there was a need for VLs to perform chemical experiments in a remote format. These reasons have led to a gradual expansion of the use of VLs in the general education system. The transition to online learning due to COVID-19 in 2020 was a turning point for education. This experience has highlighted the need for accessible online labs. The only correct solution was VLs, which ensured the continuity of laboratory scientific education at that time. The era of the pandemic provided an opportunity to get acquainted with the VL, which increased the popularity of the platform and strengthened their place in the general education system (Abdurazova, 2025).

2.1.5 Advantages of Virtual Chemical Laboratories

Chemistry is a subject with increased danger, and for this reason, when working in a chemical laboratory, it often happens that experiments are not carried out due to toxicity, difficulty in performing, and limitations in providing the necessary laboratory equipment and chemicals. Many educational institutions in developing countries face a few challenges in setting up traditional chemical laboratories. These include the following reasons (Ali & Ullah, 2020):

1. Providing a laboratory room with chemical reagents and equipment is expensive (Hoole & Sithambaresan, 2003).
2. A small mistake in laboratory work can lead to harm to students and the teacher.
3. Repeating the experience requires a lot of time and resources.
4. Sometimes students may be embarrassed to ask their teacher so that the teacher can repeat the procedure again (Ali et al., 2014).

Thanks to the integration of VLs into education, many subjects of natural sciences have increased their advantages. Another advantage of virtual labs is that students can receive real-time feedback, which gives them a chance to correct mistakes and immediately understand theory (Banihashem et al., 2022).

Among the new studies published by researchers Yang et al. (2024), the benefits of VCL are claimed. In the natural science understanding, chemistry is a discipline that studies microscopic particles and macroscopic matter. With the traditional approach to learning, it is difficult to explain abstract chemical phenomena to students. Scientists have tried to realize valuable knowledge through visualization of educational information in a virtual environment. However, the simple involvement of students was not enough to master the material. To solve this problem, the study used spherical video-based virtual reality (SVVR) to create a realistic learning environment. This approach is aimed at developing abstract concepts and improving laboratory skills in students with SEN. Thanks to this method, the SVVR authors ensured that students began to improve their academic performance in the classroom, and their motivation for the subject increased significantly. Also, the students who studied using this method demonstrated a positive attitude towards chemistry.

2.1.6 Comparative Analysis of Virtual and Traditional Laboratory Practice

Modern VLs allow you to change the sequence of work, providing real-time interactions with laboratory utensils and substances (Darby-White et al., 2019). This platform is particularly suitable for distance learning, as it can be used anytime, anywhere (Jensen et al., 2004). Another advantage of this platform is to conduct experiments that we cannot do in real life in practice and economically require less cost for devices and reagents (Wolski & Jagodzinski, 2019).

According to Lynch (2016), the use of VLs has several advantages:

1. Accessibility. Anyone can have access to the VL from anywhere and at any time.
2. Quick feedback. Students receive quick feedback from the software.
3. Less cost. VLs require less costs for chemical equipment, reagents, and apparatuses.

In traditional laboratories, students conduct experiments with the help of a teacher's guidance, without which it is difficult for students to perform an experiment. Therefore, in some VCLs, experiments are accompanied by text instructions. These

text instructions are displayed on the screen, and they tell students how to do the work step by step, which reagents or chemical utensils to use when working. Students' complete experiments in stages and on time. When compared in the cost-effective research plan by Wolf (2010), virtual labs reduce costs and simplify laboratory equipment maintenance, while at the same time, the tool provides students with access to a digital environment. The author studied the effect of VLs during lectures and laboratory work. As a result, the results showed that while working with virtual labs, students can greatly benefit from the platform. Similarly, Alhashem et al. (2023) also noted about the cost-effectiveness of VLs that is more economical than a traditional laboratory, since it does not require many resources, such as reagents, apparatuses, and equipment.

In his research, Babateen (2011) explored the fundamental differences between virtual and traditional labs. It turned out that traditional laboratories limit the physical location and time of students, while VLs, on the contrary, destroy all these barriers. The VL has multimedia resources, visual and audio accompaniment, and thus facilitates group or individual learning. However, since traditional laboratory work is based on a specific curriculum, teaching in a large group and by book, which makes it difficult to replace a completely traditional one with a VL. The main feature of virtual laboratories is the ease of use and continuous updating of new material aimed at achieving objectivity and interest in learning. With the growing popularity of the virtual educational environment worldwide, it leads to new developments of improved versions of virtual technologies in the field of science.³ One of those who conducted a practical experiment was Elkhouky (2021). The author investigated the connection and perceptions of VLs with students, teachers and laboratory assistants. As a result of the study, all participants showed a positive attitude towards VLs, emphasizing their potential in teaching and learning.

The authors Kay et al. (2018) also studied the student's perceptions. The study says that VL has further strengthened knowledge in a positive way. Performing laboratory work effectively requires a wealth of theoretical knowledge and laboratory

experience that is difficult to achieve using traditional laboratory teaching methods. The VL is designed to facilitate effective training and the acquisition of new skills in laboratories. The data obtained confirmed the statement that students have a positive attitude towards the use of the virtual environment. There were some problems during the virtual experiments, but the students reported that thanks to the VLs they were able to prepare for traditional laboratory work. The key advantage of the VL was that it allowed students to visualize chemical phenomena outside of a traditional laboratory. The study confirms the conclusion that pre-training students increases their readiness and productivity in real laboratory conditions.

Many VLs provide a virtual world with a 2D or 3D interface that demonstrates chemicals, laboratory equipment, and protective equipment on the screen. The software reacts in real time, and users can perform experiments by clicking on the mouse or using touch screen gestures. There are also more sophisticated versions of the chemical laboratory in the form of VR and AR. These immersion technologies allow users to experience a physical presence by conducting chemical experiments on their own in the laboratory. Despite the complexity of these methods, all VLs have a common goal to ensure safety, accessibility and an interactive space for practical tasks. These technologies provide an opportunity for freedom of action, monitoring the results of tasks, and give the right to make mistakes without risks or resource constraints, which is especially important for a contingent with different learning opportunities (Rutten et al., 2012).

2.2 Inclusivity in Science Education

2.2.1 Students with Special Educational Needs in Inclusive Education

Inclusive education is a worldwide phenomenon where all principles and practices are based on human rights and social justice. It suggests that students with SEN should study with their peers in the same group. To achieve this goal, teachers in inclusive classrooms play a major role through their interactions with the class (Rambo, 2006).

When asked which categories of students with SEN would benefit from an inclusive type of education, many scientists have been involved (Demchenko, 2015; Lindsay, 2007; Humphrey & Lewis, 2008). In their writings, they argue in the same way that children whose education requires additional resources, whose educational needs go beyond standard education, should be considered as students with SEN.

According to the Rules for assessing SEN, according to the law of the Republic of Kazakhstan, there are two groups of children with SEN. The first group includes children with difficulties assimilating educational materials due to a lack of mental function (mental performance, attention, perception, memory), as well as subsequent children with disabilities (Ministry of Education of the Republic of Kazakhstan [MP RK], 2022):

1. Students with hearing impairments (deaf and hard of hearing with an average hearing loss in the speech area from 40 to 80 decibels) with general speech underdevelopment of levels 1-3;
2. Visually impaired students (blind with complete visual impairment, with light perception or residual vision up to 0.004 and visually impaired - with visual acuity from 0.05 to 0.4);
3. Students with intellectual disabilities (with mental retardation);
4. Students with speech disorders (with general speech underdevelopment of levels 1-3, phonetic and phonemic speech underdevelopment, rhinolalia, severe stuttering, dysarthria, writing disorders (dysgraphia, dyslexia));
5. Students with disorders of the musculoskeletal system;
6. Students with emotional and volitional disorders (disorders of social interaction (autism) and communication, behavioral disorders and difficulties);
7. Students with complex (combined) disabilities.

The second group of children with disabilities does not have impaired mental abilities and physical development, whose SEN are justified by socio-psychological obstacles that do not include them in the educational process:

1. Children with microsocial and pedagogical neglect, raised in families from socially vulnerable groups of the population;
2. Children experiencing difficulties in adapting to local society (migrants, Candace, refugees);
3. Children with disabilities.

Inclusive learning is promoted as a tool to improve educational outcomes and eliminate barriers and discrimination. However, the term inclusivity is a complex concept, and it takes a variety of approaches in practice. While there are disputes about the veracity of these practical points, referring to partial studies, others look at the problem in a broad context. Paradoxically, the less inclusive an individual is, the more approaches and involvement they have in the educational process. As a result, it is necessary to focus on individual and practical aspects, as well as consider the internal structure in the field (Lindsay, 2003).

The author of Moriña (2019) believes that all students, despite the types of limited opportunities, students should receive equal access to participate in quality education. For several years, inclusive practices and principles have been slowly introduced into educational programs, allowing people with disabilities to participate fully in the classroom. If we compare secondary and higher education, then inclusive education has been introduced only in secondary education. And many universities do not consider inclusive education in their curricula. The author has explored several strategies in his work that can improve inclusive learning for all students. One of the main themes is the accessibility of the environment, without any physical barriers. It is extremely important for students that universities have facilities where all users can have equal access. The next strategy is that higher education environments should consider the delicate transition of students with disabilities, especially during the first year of study. In inclusive education, as Rambo (2006) argued, teachers are an important part of learning. The author has shown that depending on the teacher's attitude towards a student with SEN, they can be involved or excluded from the subject.

2.2.2 Provision of Inclusive Education in the Natural Science Field

Over the past twenty years, the notion has emerged that effective scientific education is vital for economic growth in the coming century. It is also believed that a scientific way of thinking is necessary to participate in the democratic decision-making process. To master scientific concepts, students need special conditions in which they can think deeply about situations. In many schools, social changes such as migration, demographic change, and changing values can be noticed, resulting in a diverse student environment. Due to the diverse environment in natural science education, many problems are solved considering different aspects, such as culture, language, scientific literacy, gender. In natural science education, ensuring inclusivity and diversity is a serious challenge for teachers. To solve this problem, it is necessary to develop individual training to meet the different needs of students (Mamlok-Naaman, 2024).

Teaching individuals with SEN in natural science education has become an urgent issue over the past decade, not only because of the increasing number of students in regular classrooms, but also because the teaching experience in traditional natural sciences requires a change for people with SEN (Comarú et al., 2021).

As revealed by Jeannis et al. al. (2018) students with special learning needs often face the following barriers during laboratory work:

1. Organization of space and ergonomics
2. The experimental practical part
3. The influence of the external environment on learning

The authors Jeannis et al. (2020) concluded that inclusive learning in science is when it is convenient for both body and soul. A student cannot study if the ergonomics in the laboratories are poor or if the supervisor shows negativity towards the student, that is, the external environment affects the person mentally and physically. A health restriction in science is not a “disease”, but only the influence of poor spatial planning and the environment.

2.2.3 Criteria Assessment of Accessibility of Virtual Laboratories for Students with SEN

In a large system review by Sison et al. (2024), researchers examined a huge amount of information and concluded that digital educational platforms are a good visual. They have proven that digital educational platforms work well in practice as a learning tool for teaching, but only if they are inclusive. It's chilling that we don't just give the student a “computer”, but adapt each task to each child, including their difference in cognitive load. The authors assessed accessibility using the VILIS (Virtual Laboratory in Learning Systematics) method, which allows us to identify three key assessment vectors: technological ergonomics and navigation barriers, multimedia redundancy, and cognitive accessibility of content.

- Technological ergonomic: This type of blog criterion was highly appreciated due to intuitive navigation and the simplicity of the interface. For people with motor impairments and cognitive thinking, this parameter becomes crucial because it minimizes the complexity of management and directly sets the bar for emotional comfort.

- Multimedia redundancy: The use of educational, short videos, high-quality graphics and sound accompaniments in inclusive education compensates for the gaps that arise in the traditional laboratory. For students with sensory impairments (hearing, vision) or ADHD, multimedia provides the necessary “sensory redundancy”, allowing them to perceive complex chemical concepts.

- Cognitive accessibility of content: The ability to split the material into small interactive blocks makes it easier to complete the task. Especially for people with ASD, this criterion is the most important, as it helps to avoid cognitive overload.

Modern international experience emphasizes the need to develop criteria for evaluating digital adaptive content for inclusive education. In this regard, Arkabaev et al. (2025), a study devoted to assessing the availability of educational materials in a virtual environment, deserves special attention. The authors identify several evaluation

criteria, such as intuitiveness, simplicity of the interface, the presence of duplicate prompts, adaptability and flexibility of settings.

- Intuitive and simple interface. For students with visual, hearing, and autism spectrum disorders, the complexity of management is a barrier to learning the subject. Therefore, minimizing cognitive load through a simplified interface is a sign of accessibility.
- The presence of duplicate suggestions. An important result of the work was the effective use of multisensory signals. Within the framework of inclusive learning, this means that the VCL is assessed as accessible only if it offers flexible suggestion functions.
- Adaptability and flexibility of settings. The researchers emphasize that the ability to customize the environment to the individual needs of the participant (work pace, difficulty level, contrast) allows you to create unique educational trajectories.

Based on this, if the work of Sison et al. (2024) sets the general quality framework for VLs, then the study by Arkabaev et al. (2025) examines these quality frameworks with an emphasis on adaptability. The synthesis of these criteria helps to create a comprehensive criteria system that aims to maintain an inclusive environment.

Deriba et al., (2024) also identified several features of the availability of VLs and evaluated them according to certain criteria. First, the virtual environment is made available by the presence of navigation assistants, thereby making it possible to perform experiments without using a mouse. The second function of VLs is multimodal interfaces that reproduce visual information, audio and text information. And the third assessment method is adaptability, which implies the ability to customize the interface (size of formulas, contrast) to meet the SEN of students. In this paper, the concept of “accessibility assessment” treats not only the technical aspects of the interface, but also how the virtual chemistry environment adapts to the cognitive abilities of students with SEN. Virtual labs are mostly competently structured, that is, they simplify complex experiments by dividing them into simple and logical steps, which is critically important for students with cognitive impairments. And, the use of clear instructions,

such as the use of simple language, hints, navigators significantly reduce the cognitive load when studying abstract concepts of chemistry.

2.2.4 Effectiveness and Potential of Virtual Laboratories in Inclusive Chemistry Education

The use of computers and various digital tools in chemistry teaching increases the effectiveness of teaching in inclusive classrooms. The authors Nsabayezu et al., (2022) studied how students with hearing and visual impairments can easily access chemistry instructions. As a result, it was found that students with hearing impairments perceive lessons with video and photographic materials well, which improves their understanding of complex chemical concepts. And for students with visual impairments, computers provide the opportunity to listen to videos and audio materials on chemistry lessons. It is more difficult for students with visual impairments to record notes in lessons, and students can listen to the lesson again during independent work based on recorded lessons on the computer.

Other authors have also worked on the benefits of virtual labs. For example, Cooper et al. (2014) investigated that students with impaired motor function could fully participate in laboratory activities when using VLs. Due to the fact that students can independently manage the laboratory environment and perform chemical experiments, VCL can replace traditional laboratory classes. The authors of Sualo et al. (2014) found that VLs accompanied by sound descriptions and tactile feedback allow students with visual impairments to fully immerse themselves in laboratory activities. These functions allowed the students to understand the process and the results of the experiments, even though they could not see the visual cues. Research by Barker et al. (2015) demonstrates that a VL increases the engagement and understanding of children with autism compared to traditional laboratories.

Over the years, the use of VLs in the educational field has been continuously increasing, thereby making this digital environment more popular in the general education system. Various forms of student inclusivity, ranging from visual and physical impairments to neurological diseases, can fully participate in chemistry

education. A VL can break many limitations by offering students innovative methods of interacting with chemical concepts.

The growing demand for inclusive education has contributed to the proliferation of virtual labs. Their main difference from traditional laboratories is that they are adaptive and they can meet the diverse needs of students, including those with disabilities. This aspect of VLs demonstrates the desire for a more inclusive and equitable education, which further increases their applicability and popularity (Abdurazova, 2025).

In an educational environment, virtual labs include step-by-step instructions for completing work, navigators, explanatory videos, and tests to consolidate practical work. Such platforms can be adapted to the individual needs and work pace of each student, making them universal learning tools for inclusive science education. The recognition and development of VLs have been significantly influenced by advances in technology and new developments in the educational curriculum over the past few decades (Webb, 2005).

And there are other authors who have also proved the importance of a VL through research. For example, Ghergulescu et al. (2018) conducted a small experiment on atomic structures in a VL for students with SEN. Students working in the VL mostly learn independently, thanks to the introduction of personal functions, and survey-based learning was also observed during the study. These classroom teaching methods, combined with interactive activities and multimedia tools, turn the lesson into a fun and interesting learning environment. In the VL, students become dramatically active due to independent learning. Students with SEN in the experimental project studied the topic of atomic structures, where they analyzed the main terms of chemistry, such as the structure of atoms, molecules, and isotopes. Participants interacted with atoms in a virtual environment, built atoms using this information, which is available in the periodic table, and could also create molecules and isotopes. This study was not aimed at students with different types of inclusivity, only students with hearing impairments participated. As a result of data analysis, the authors concluded that while working with

the VL, students with SEN increased their mental characteristics, such as engagement, mobility, flexibility and originality. This observation of students shows the introduction of VLs into the SEN.

Similarly, Baladoh et al. (2016) did the practical part with students with hearing impairments. Students built electronic circuits in a VL, thereby developing practical experience. The results of the experiment showed that the virtual environment allows students to create and test different electronic circuits. These results also show the effectiveness of the VL in improving student academic performance and practical skills in using electronic circuits.

2.3 Challenges and Prospects of VCL Development for Students with SEN

2.3.1 Challenges of Virtual Laboratories for Students with SEN

In previous sections, we talked about the advantages of virtual labs, but there are a couple of authors who saw some limitations in using the platform. According to Abdurazova et al. (2025), students with SEN may encounter obstacles when working with VCL. A significant problem is the design and decoration of the digital environment. There are different types of platforms that are virtual labs. Most of the free versions of such platforms do not count on the full availability of the function. They may lack features such as speech audio recordings, soundtracks, and alternative input methods, which are very indispensable for students with hearing, vision, and musculoskeletal disorders. In addition, some virtual labs do not support adaptability, which causes participants to have problems completing the task. This is the downside of the virtual environment, especially when students with cognitive and neurological impairments are working, which leads to cognitive overload or anxiety.

In addition, the author noted the teaching experience and knowledge. Teachers should use VL competently and should be aware of its functions and capabilities. They also need to know the special needs of the students to adapt the VL for them. However, not all teachers have experience in using virtual platforms in these areas. During experiments in a virtual environment, several technical difficulties may arise that must

be resolved with the help of a teacher. For example, you need to be able to choose the right device that supports the platform. Students with SEN may also need special assistive technologies to interact with VL. Such requirements can cause difficulties for students who lack additional resources or technical support.

Another factor that is an obstacle to virtual labs is the attitude and perception of stakeholders. Many teachers, students, and parents may not approve of learning with virtual labs, considering them less valuable and reliable than traditional labs. This location may affect the adoption and use of virtual labs. There may also be an organizational obstacle. This is due to a lack of funding and policies to support the implementation of virtual labs for schools and universities. They may also encounter difficulties with the curriculum and assessment system during the integration of VLs. Addressing these issues requires concerted action by educators, policy makers, developers, and researchers. And this, in turn, includes improved platform development, training and support from teachers, ensuring technical accessibility and encouraging a positive attitude towards VLs. Perhaps in the future, with such changes, VL could become more inclusive and support inclusive learning. The main barrier to inclusive learning is due to technical aspects, reducing the effectiveness of using VLs.

Despite the promising results, it should be noted that the VL does not solve physical problems one hundred percent. The effectiveness of the VL is mainly influenced by the design and variety of functions of the instrument, as well as the type of inclusivity of the student. Therefore, teachers should additionally guide and provide support for students so that they can benefit from the experience of working in a virtual environment (Barker et al., 2015).

The authors Chang et al. (2020) had similar results, they investigated the accessibility of VLs for students with learning disabilities. The authors concluded that not all VLs are accessible to students with disabilities. For example, for students with visual impairments, the digital environment does not provide additional features such as audio descriptions. And for students with cognitive and physical disabilities, the platform does not provide an input program. This is a completely solvable problem,

but the developer needs to prioritize the accessibility of the VCL during development and also provide teachers with tools and knowledge to adapt the VCL to the special preferences of their students.

Other methods to eliminate these problems are to eliminate thorough testing and obtain user feedback during overhead line development. As well as the introduction of technical support and resources into the platform can fix problems when working with overhead lines.

2.3.2 Future Direction of VCL in Inclusive Chemistry Education

Many researchers (Abdurazova et. al, 2025; Berezi, 2025; Alhashem & Alfaiakawi, 2023,) note in their works that VLs may become an important part of educational programs in the long term, providing flexibility and accessibility of education. For example, Abdurazova et al., (2025) in her work spoke positively about the VL for inclusive learning. Technological advances such as VL, AR, AI, and data analysis are opening new doors to create exciting and personalized VLs in chemical education. Despite this, in the future, when implementing these technologies, it is necessary to pay attention to pedagogical and inclusive aspects. According to the hypotheses of the listed authors, the future of VCLs in terms of inclusive education is shaped by three key areas of development:

First, it concerns the transition of the VCL to multimodal and immersion interfaces. As Ali et al. (2014) and Edwardset al. (2019) emphasize, the introduction of immersive VR and tactile feedback into learning, where students with hearing impairments can participate fully in the chemical process using sounds and vibrations. The development of gesture recognition (Wolski & Jagodziński, 2019) may also make it easier for children with hearing or speech impairments. In the future, improved VCL, where built-in functions to minimize physical activity will open up the possibilities of managing a chemical laboratory for students with musculoskeletal disorders.

Secondly, the future of inclusive learning in chemistry is closely linked to adaptive function applications (Banihashem et al., 2022). It is assumed that in the future, the VCL will be additionally connected with artificial intelligence, and the cognitive

load of students will be assessed on the basis of artificial intelligence, as well as all points with the complexity of the interface will be adjusted automatically.

Finally, the standardization of VLs is based on universal design. The work of Deriba et al., (2024) and Girmay et al., (2026) highlights that the platform does not fully guarantee an inclusive environment. The authors expect that in the future, the virtual chemistry environment will provide full adaptability for inclusive learning that can ensure equal access and learning opportunities for every student, despite physical and cognitive disabilities.

METHODOLOGY

3.1 Research context and setting

In recent years, the educational program has been actively adapting to inclusive education, as well as modernizing digital technologies in the natural sciences. However, the discrepancy between the established requirements of the state and the real savings of traditional chemical laboratories is clearly noticeable. This situation shows the importance of finding alternative digital methods to address these gaps. The virtual chemical environment is not only a substitute for traditional laboratories, but also an adaptive environment where different individual needs can be realized.

This work was carried out in schools with the status of gymnasium, comfort and private school in the cities of Kaskelen and Shymkent. Each school had a different level of chemical laboratory equipment. Some schools have separate laboratory rooms and are equipped with a variety of chemicals and equipment. For example, in private schools, the chemistry room has a fume hood for experiments and a separate laboratory room. As for the gymnasium-level school, there were no fume hoods for laboratory work.

The choice of these educational institutions was not random and was determined by the following factors: the status of the school's inclusivity, the availability of laboratory facilities, and the administrative readiness of the management.

The literature review stated that inclusive children are considered into 2 groups according to the law of Kazakhstan. We were looking for exactly 1 group of children with SEN who can cognitively perceive a subject. Unfortunately, the second group cannot participate in our work because they do not have the opportunity to study in a classroom with other students. For this reason, we have excluded children who study at home. Naturally, after we removed this group, the number of participants in the study will decrease dramatically, but our main goal is not the number of participants, but the quality of work, how effectively children with educational needs will work on the VCL platform. Students with different types of health restrictions, with an age range from 11 to 15 years, took part in this work. At this age, students have the necessary

theoretical knowledge and a sufficient level of work in a digital environment. The study participants studied in grades 6, 7, 8, and 9. According to statistics, children with disabilities mostly study up to the final ninth grade, and for this reason, it was difficult for us to find grades above ninth grade. They also chose the sixth grade, but they still do not study chemistry according to the curriculum. But starting from the fifth grade, students in our country study the subject of natural science, and this subject already has basic topics about chemistry. So, they were already familiar with the term's atoms, molecules, solutions, chemical and physical phenomena.

Most schools in the Republic of Kazakhstan do not include additional digital technologies in the curriculum, which leads to the complexity of the concept of chemical topics. This study focuses on inclusive children and shows in practice that VLs significantly improve the academic performance of students with SEN.

3.2 Design of the study

Research is of practical importance, testing and evaluating the accessibility of VCLs for students with SEN. To achieve answers to research questions, a mixed research method was chosen, combining a qualitative and quantitative method. These research approaches will be able to assess not only the educational outcome, but also the pedagogical and technical accessibility of the VCL for students with SEN. The structure of the research method includes four related stages:

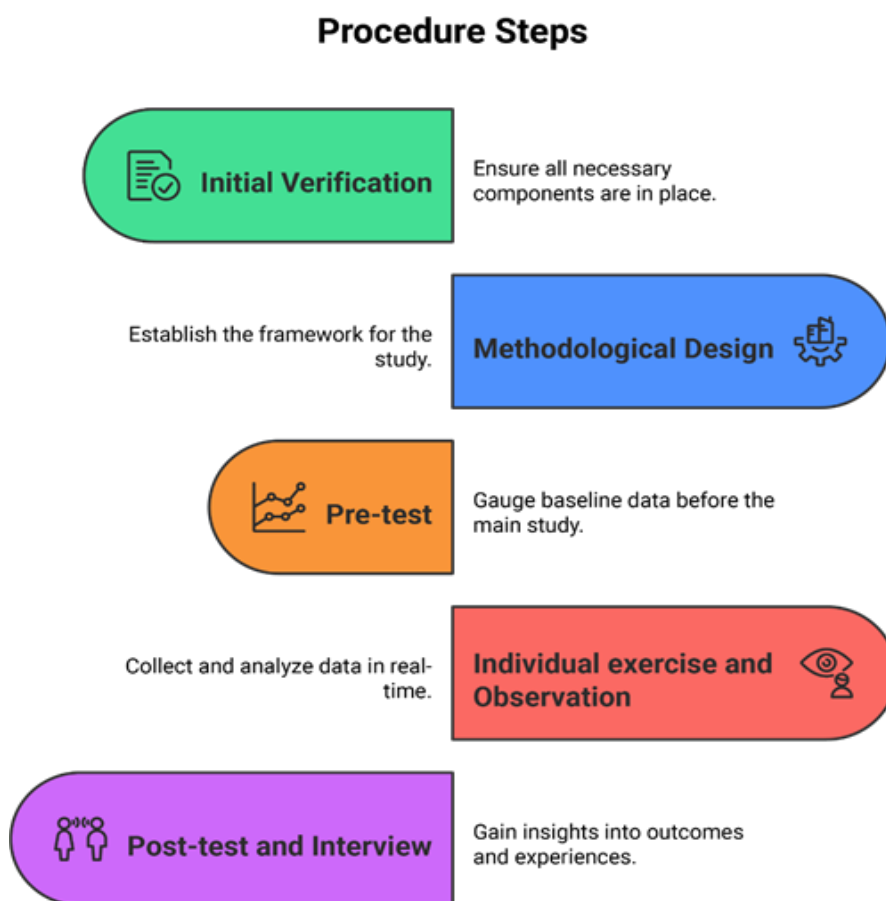
1. The initial verification stage. At this stage, all available VCL have been checked for technological and pedagogical verification. The main goal was to determine the baseline level of VCL availability prior to the start of the study.
2. The method selection stage. After checking the digital instrument, suitable methods based on quantitative and qualitative analysis were established.
3. The examination stage (pre-test). Prior to working with VCL, students with SEN were given introductory tests to determine the level of chemical theory.
4. The observation stage. Structured observation was conducted during the students' independent work. The main purpose of this method was to find out whether a student with an SEN would be able to learn independently in a digital environment.

Special attention was paid to the parameters of the relationship, such as understanding the performance of the work, the speed of navigation and the ability to independently experience chemistry without assistance.

5. The assessment stage (post-test). After completing the class cycle, the final test was conducted in the last lesson. The results of the pre- and post-tests were compared with each other. The comparative approach made it possible to assess the academic growth of students with disabilities before and after VCL's intervention in chemistry.

6. The interview stage. The final stage of the research is a structured interview method. Through interviews, participants can share their experiences and chemical experiences, and thus we get in-depth data on the assessment of the availability of VCL, the level of psychological comfort, and difficulties in performing the experiment.

Figure 3.1 Structural diagram of the stages of experimental part



The combination of qualitative (interview, observation) and quantitative (pre- and post-test) methods increases the reliability and objectivity of the conclusions of this study. The logical structure of this work is shown step by step in Figure 3.1.

3.3 Research Participants

The research contains a targeted sample, as we have focused on students with SEN and who understand basic chemical terms well. The ages ranged from 11 to 15 years old, including children in grades 6-9. According to the program of the Republic of Kazakhstan, sixth grade children do not take chemistry, but from 5th grade to 6th grade they take a science subject. In this subject, children get acquainted with the directions of natural science subjects such as chemistry, biology, physics, geology, and astronomy. In the chemistry section, they get acquainted with basic topics in chemistry, in particular: atoms and molecules, chemical and physical phenomena, the state of aggregation of substances, solutions, etc. Thanks to this factor, we were able to cover a couple more participants, which further enhanced the analysis of the results. 17 participants with different types of SEN participated in the pedagogical experiment. The study was conducted at public and private educational institutions. As we have already emphasized, students with different types of SEN participated in the work, and for the same reason, we divided the participants by type of inclusivity, which made it possible to evaluate the different accessibility functions of the VCL interface:

1. Students with a speech defect evaluated the performance of a chemical experiment without having to pronounce it.
2. Students with cognitive impairments - assessment of understanding of abstract terms.
3. Students with impaired social interaction and behavior - assessment of long-term retention of attention to a chemical experiment.
4. Students with motor disorders - assessment of accessibility of chemical process control.
5. Students with hearing disorders - assessment of sensory perception (sound accompaniment).

6. Visually impaired students - assessment of sensory perception (visual ergonomics and contrast).

7. Students with special learning difficulties (dyslexia) - assessment of the perception of textual information and cognitive load.

These participants were selected according to the criteria of thinking, that is, we did not consider children with low degrees of thinking ability. And participants with cognitive impairments can learn and adapt to learning, so we did not exclude children with cognitive impairments. They may have difficulties with abstract thinking and logic, but this part can be solved with the right approach to learning. The next criterion is knowledge of chemistry, that is, the student must have previously been familiar with this subject and with the basic topics of chemistry. The last criterion is the ability to work with digital technologies. According to this criterion, it was easy to find students with SEN, because modern children can safely use electronic gadgets. And a VCL, it's like a game, everything is done instinctively and there is no difficulty in thinking while working.

3.4 Ethical Considerations

The data collection stage adhered to all ethical standards, ensuring complete anonymity for the study participants. Prior to the start of the study, receipts were created to allow the experiment to be conducted with students from the SEN. The permits were obtained in paper form from the director and electronically from Google Forms for parents. These letters spoke about maintaining anonymity, that all personal data about the student would be encoded (Student 1, Student 2, Student 3 ...), and if the student got tired during the experiment, he had every right to stop the pedagogical experiment. In this regard, the student can freely express his right to participate, there was no pressure on our part to participate in the experiment. Of course, due to such reasons, there were exceptions related to consent to participate. It happened that the parents refused, the student from the SEN did not want to participate himself, or the school itself could refuse to cooperate in a pedagogical experiment. For these reasons, it was very difficult to find participants from the SEN.

3.5 Data Collection and Instruments

The tools of the quantitative method (pre- and post-test) that were used to determine the change in academic progress consisted of six questions. The format of the tests depended on the type of inclusivity. For example, to improve accurate results, additional drawings were added to the test for students with DD and ADHD. The questions were based on the curriculum of the Republic of Kazakhstan based on the book by Ospanova and Verkhovtseva for grades 6-9. The questions for the pre and post tests were formulated according to the levels of complexity according to Bloom's taxonomy (low, medium, high). At the end, all the questions were checked with the teacher on the subject. And according to the advice and instructions of the teachers, the questions were changed during the creation process. The pre- and post-test questions were logically compared with each other to eliminate confusion during the test. The tools were flexible, meaning that if it was physically difficult for a participant to write a test, we allowed them to answer the questions verbally and recorded the answers. Since the coverage of the age range was diverse, therefore, the questions were created on several topics according to the degree of study. We considered such topics as: *“Chemical and physical phenomena”* for grade 6, *“Solutions”* for grade 7, *“Atoms and Molecules”* for grade 8, *“Halogens”* for grade 9.

In the qualitative method, questions for structured interviews and a protocol for pedagogical supervision were prepared. The interview contains six questions, and the main purpose of these questions was to get an in-depth answer about the chemical experience of the students. The completed interview questions were evaluated using expert opinions in Google Forms. In our earlier work, the experts' estimates for this work were presented (Absattarova et al., 2025). Since the research includes several areas: chemical sciences, inclusive education, digital technologies, the opinion of one expert on the questions posed would not be enough for a full assessment. For this reason, five experts participated in our work: a supervisor, a PhD student, a chemistry teacher (moderator), a psychologist and a defectologist. The experts evaluated each question according to the following criteria: clarity, content coverage, relevance to the

purpose of the study, usefulness for analysis, ethics of compilation and assimilation. The scores for these criteria were obtained using the following answer options: does not match, partially matches, mostly matches, fully matches. Thanks to these experts, the final version of the interview questions has been changed and compiled. During the interview, in order to remove tension from the participants, the pedagogical experiment was conducted in an informal setting using suggestive questions.

The structured type of observation contained a protocol with a table where the time of execution, the psychological state of the student, the number of requests for help, and barriers to performing a chemical experiment were noted. And the criteria for the accessibility of the VCL in terms of navigation convenience, understanding of the task, etc. were recorded. The main purpose of the observation was to assess the technical, cognitive accessibility, as well as the psychological comfort of the VCL for students with SEN.

The data collection was carried out to obtain in-depth data on the chemical experience and on the availability of VCL. The data was collected in two different periods due to difficulties in obtaining permission for a pedagogical experiment from the principal and parents. The first pedagogical experiment began from November to December 2025, and the second period began from February to March 2026. The data collection process was organized in the format of an individual lesson, which reduced distractions during training. Also, the students from the SEN were of different ages and inclusivity, the lack of computers for working with the VCL, and student attendance also affected the joint type of learning, these reasons did not allow recreating group learning with participants. Only an individual approach could solve this problem, and with this method it was possible to concentrate on one type of inclusion. The lesson was conducted in an individual chemistry classroom in a quiet environment, which is especially important for children with Development Delays (DD) and ADHD. One session lasted 30 or 40 minutes, it all depended on the students' overwork. We took the student from the SEN to the chemistry room ourselves and after the session with the student we took him to the next room for the next lesson.

The VCL was tested on the researcher's computer, which could withstand working with it. Because some VCL, such as PhET, Nobook, worked only with good shutter speed, and old computers often lagged when working in a virtual environment because of this reason. Chemical experiments were performed using mouse and keyboard controls. For example, students from the SEN searched the search panel for the necessary equipment or chemicals to simplify the search process. However, if participants who were missing the upper part of their limbs had participated in the study, then additional equipment (a command voice) would have to be added in this case. And in this study, there are no participants with this type of restriction, so we did not consider this part.

As for the VCL, many of the available platforms had adaptive features such as soundtracks, magnification of instruments, designs with contrasting visualizations, some even had realistic boiling vibrations, explosion sounds, which even children liked. Laboratory platforms like PhET and Nobook were affordable and had good graphics and using them in research was a good solution. There was also a third type of VCL, which was called PraxiLabs. And secondly, on the platform, work could be done on a specific topic, which limits free action in a digital environment. Thirdly, the chemistry topics that were on this site were difficult for students at the school level. Because of these reasons, we only worked with two types of VCL: PhET, Nobook.

The data were obtained using qualitative and quantitative research methods. The data collection process was divided into three stages:

The first stage of quantitative data collection was carried out through a pre-test, which consisted of six questions to determine the basic level of knowledge in chemistry. In addition, an introductory lesson was held at the beginning to familiarize with the VCL platform for stress relief.

At the second stage, high-quality data was obtained based on structured observation. This time, the student performed chemical experiments on his own without outside help, and the researcher played the role of an "observer" and did not interfere in the learning process. Then, according to a pre-prepared protocol, the

behavior of the participants from the was recorded. The following types of observations were noted in the protocol: time spent, the number of repeated attempts, the number of requests for help from the teacher, speech and body signals of dissatisfaction and joy at receiving the result.

And at the third stage, data on the post-test was collected to assess the growth of knowledge among students, in addition, in-depth data on the availability of VCL was collected through a structured interview. The pre- and post-tests necessarily included images of the chemical process, which created a visual support for abstract thinking, and this is especially important for children with cognitive impairments.

Quantitative data was recorded by scores, manually, and qualitative data was recorded using a voice recorder in the form of an audio recording and a protocol. The resulting audio recordings were subsequently encoded or shaded to ensure the complete anonymity of the participants and were subsequently verified using thematic analysis. Special cards with symbols and pictures with a Likert scale were prepared for participants with speech impairments during the interview. These devices facilitated the conduct of interviews, which ensured accuracy and evidence of their answers. There was no time limit for conducting tests and interviews. This made it possible to eliminate the “test anxiety” factor and ensure the psychological comfort of the participants. All these descriptions of the analysis method are indicated in Table 3.1.

Basically, the data collection process was carried out in the first or second lesson. The reason for the choice is simple, and it is related to the activity of the participants. Usually, students are active at the beginning and until the middle of the lesson, and already at the last lesson they get tired and work passively in the lesson. Another reason to conduct an experiment in the first lessons is because of the limits on the participation of children with SEN in lessons. In some schools, students with SEN study until the third lesson and then go home.

Table 3.1 Structure of individual practical sessions

<i>Method</i>	<i>Analysis type</i>	<i>Order</i>	<i>Instrument</i>	<i>Purpose</i>
<i>Pre-test</i>	quantitative	Session 1	Test	RQ-1: “Assessment of academic growth”
<i>Post-test</i>	quantitative	Session 3	Test	RQ-1: “Assessment of academic growth”
<i>Observation</i>	qualitative	Session 2	Protocol	RQ-2: “Fixing the relationship between the test subject and the VCL”
<i>Interview</i>	qualitative	Session 3	Interview questions	RQ-3: “Chemical experience analysis and accessibility assessment”

3.6 Validity and Reliability

To ensure the validity and reliability of the preliminary and final testing tools, an assessment of expert agreement and internal consistency was carried out in all grades (6–9). Four experts in the given subject area independently evaluated each test, after which the Kendall coefficient of agreement (W) was calculated to determine the degree of consensus between them. Internal consistency was checked using Cronbach's alpha coefficient (α).

These statistical indices provided robust evidence for the stability and consistency of the assessment tools, thereby validating their use for comparative analysis across all studied grade levels.

Table 3.2. Expert Agreement and Reliability – Pre-Test (Grades 6–9)

Grade	N	Kendall's W	Chi-Square	df	Asymp. Sig.	Cronbach's α
6th Grade	4	0.853	13.644	4	0.009	0.951
7th Grade	4	0.729	11.662	4	0.020	0.930
8th Grade	4	0.705	11.279	4	0.024	0.890
9th Grade	4	0.886	14.176	4	0.007	0.931

Note. *N* = number of experts. Kendall's *W* = coefficient of concordance. *df* = 4 for all grades. Cronbach's α = internal consistency (Reliability Statistics).

All processed test data are shown in Appendix 2 (pp. 76–79).

Table 3.3 Expert Agreement and Reliability – Post-Test (Grades 6–9)

Grade	N	Kendall's W	Chi-Square	Df	Asymp. Sig.	Cronbach's α
6th Grade	4	0.915	14.633	4	0.006	0.812
7th Grade	4	0.824	13.183	4	0.010	0.819
8th Grade	4	0.807	12.909	4	0.012	0.910
9th Grade	4	0.753	12.055	4	0.017	0.938

Note. *N* = number of experts. Kendall's *W* = coefficient of concordance. *df* = 4 for all grades. Cronbach's α = internal consistency (Reliability Statistics).

As shown in Table 3.2 and Table 3.3, all Kendall *W* values were statistically significant ($p < 0.05$) for both preliminary and final tests, indicating a satisfactory level of expert agreement in all grades. For the preliminary test, the *W* values ranged from 0.705 to 0.886, while the final test values ranged from 0.753 to 0.915, indicating a strong and stable expert consensus. The Cronbach's alpha coefficients exceeded 0.80

for all instruments, with the exception of the 6th grade post-test ($\alpha = 0.812$), which nevertheless remains within an acceptable range. These results confirm that the tools demonstrate adequate validity and high internal consistency, which makes them suitable for measuring student performance in this study.

After the approval of the pre and post test questions, interview questions were developed where five experts from different industries looked at and evaluated the questions. Appendix 1 (p.75) shows the experts' ratings for each question.

Later, these issues were analyzed using the IBM SPSS program and using Kendall's W test parameter, the level of expert agreement was determined. The results of the analysis are shown in Tables 3.4 and 3.5.

Table 3.4 Expert Agreement Kendall's W-Test Statistics

Test Statistics	
N	5
Kendall's W^a	,723
Chi-Square	18,082
Df	5
Asymp. Sig.	,003
<i>a. Kendall's Coefficient of Concordance</i>	

Table 3.4 shows a high degree of expert agreement on the Kendall coefficient $W=0.723$. This indicates that, despite the number of experts, they came up with a similar answer. The static significance of the coefficient by p-value is <0.001 , which also proves the real general trend in expert opinions. Table 3.5 shows the average value analysis as additional information.

Table 3.5 Expert Agreement Kendall's W-Test Ranks

-	Mean Rank
Question_1	5,90
Question_2	3,90
Question_3	4,20
Question_4	3,10
Question_5	2,20
Question_6	1,70

Based on the results of this calculation, it can be understood that Expert 5 and Expert 1 were loyal experts, while Expert 3 showed great exactingness in evaluation. However, with the help of a high degree of conformity in expert assessments, these conclusions do not destroy the consensus of experts.

3.7 Data Analysis Plan

To ensure the full comprehensive impact of VCLs on the educational process of students with SEN, the collected data will be processed by quantitative and qualitative analysis. Quantitative data is analyzed in the Jamovi program. The data processing plan covers three types of analysis:

Quantitative analysis of test results. The results of the pre- and post-test will be initially checked for Shapiro-Wilk normality to determine the correct distribution of the data. When confirming the normal distribution, the Paired Student T-Test will be used to assess academic growth. However, if a nonparametric distribution is revealed, which is an extremely likely outcome for a small sample ($n=17$), then the results will be analyzed using the Wilcoxon signed-rank test. This method can statically justify the presence or absence of academic growth in various inclusive groups.

Qualitative analysis of the observation results. The information recorded in the protocol will be processed by descriptive analysis. The results of the analysis will be used to create an accessibility pyramid for different inclusion groups.

Qualitative analysis of the interview results. The transcripts that were obtained during the structured interview will be analyzed using the thematic analysis method. For an in-depth study of student engagement, the interview responses will be analyzed for the presence of eight motivation functions using the “octalysis” model. This model will be able to identify psychological and gaming stimulus that promote effective learning in a virtual environment.

RESULTS

4.1 Results of Academic Growth in Quantitative Analysis

To find the answer to the first research question - “To what extent does the introduction of a VCL into the educational process affect the academic progress of students with special educational needs?” - questions were created to identify changes in academic performance. Theoretical aspects were explained to the SEN students on each topic, and in the second session they themselves began chemical experiments in a virtual environment. During the sessions, only one chapter of the chemistry subject was considered, so as not to burden children with long and tedious lessons. Because of this reason, only 3 sessions were conducted with each child in individual training. On the topic of the dissertation “assessing accessibility,” the work focuses more on accessibility than on identifying progress in student academic performance. For the same reason, research work pays special attention to qualitative analyses. Quantitative analysis also provides good results, which further expands part of this study.

As mentioned earlier, the students had different types of inclusivity and age. This diversity makes it possible to divide the participants into large groups. The research adheres to the high confidentiality of the participants, for this reason, the names of all participants were changed to the codeword “Student” (Student 1, Student 2, Student 3 ...). Due to the knowledge testing, pre- and post-test data were collected, which are shown in Appendix 3 (pp. 80-81).

The study assessed the cognitive process of students in an inclusive environment when introducing VLs in the educational field. The Paired Samples T-Test was chosen as the analysis method, which allows comparing the test results before and after the intervention within the same group.

An important step in the analysis was to check the normal distribution using the Shapiro-Wilk test. The value of p equal to 0.669 confirms the adequacy of using parametric analysis methods, exceeding the threshold level of 0.05 several times. The Shapiro and Wilk test says that the data does not have critical distortions or omissions,

which allows us to extrapolate the findings to similar groups of students with similar needs in the educational sector. The information for review is given in Table 4.1.

Table 4.1 Shapiro-Wilk Test results

Normality Test (Shapiro-Wilk)

			W	P
Pre_Test	-	Post_Test	0.962	.669

Note. A low p-value suggests a violation of the assumption of normality

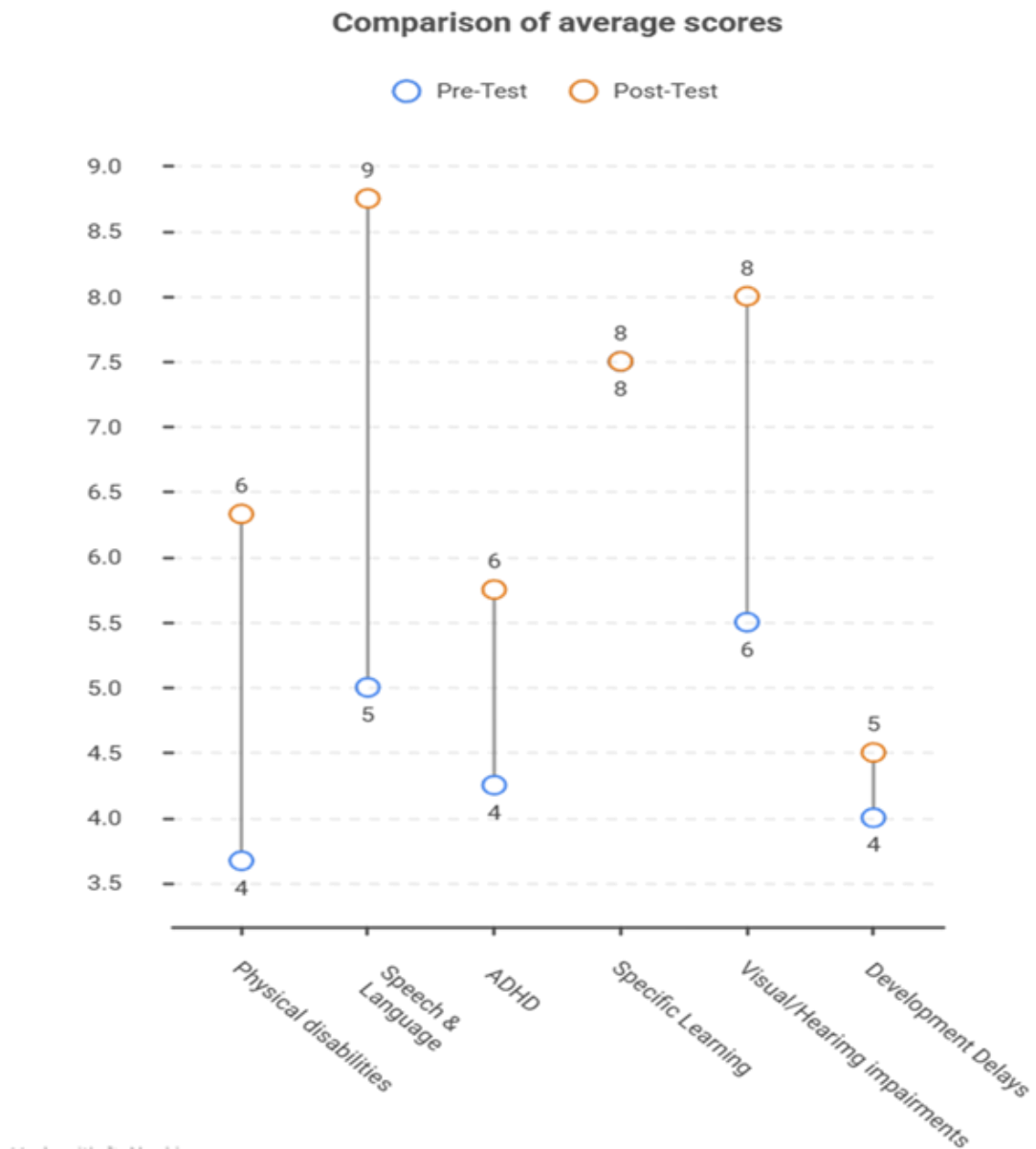
As can be seen in Table 4.3, the initial inspection of the data shows a significant positive trend. The average group performance indicator (Mean value) before the start of the educational session was 4.71 points. This assessment indicates that without specific digital support, students with SEN faced significant barriers with standard teaching methods, not reaching the average academic achievement threshold. After the introduction of virtual labs, the average student score increased to 6.88, which corresponds to an increase of about 46%. This confirms the overall dynamics of the methodology's effectiveness, based on a qualitative transition from an “unsatisfactory” or “threshold” level to a “confident average” or even “moderately excellent.” Estimating the median score before testing, which was 5 points and a further increase to 7 points after testing confirms the sustainability of the trend. This means that progress is not a series of abnormally high results of a pair of “strong” students but is widespread in the group. An important marker of effectiveness was the practical increase in the minimum score. If in the pre-test the minimum score was 2 points, then in the post-test it increased to 4 points. At the same time, the maximum limit reached the maximum threshold in the form of 10 points, which were shown by student number 4 and student number 14.

Table 4.2 Descriptions of the results before and after testing

-	Pre_Test	Post_Test
N	17	17
Mean	4.71	6.88
Median	5	7
Mode	5.00	6.00
Sum	80	117
Standard deviation	1.31	1.80
Variance	1.72	3.24
Range	6	6
Minimum	2	4
Maximum	8	10
25th percentile	4.00	6.00
50th percentile	5.00	7.00
75th percentile	5.00	8.00

To visualize the data shown in Table 4.2, Figure 4.1 provides a visual comparison of the average Pre-Test and Post-Test scores for each inclusion category. The graph shows positive dynamics in all subgroups, which is consistent with the overall increase in the sample average from 4.71 to 6.88.

Figure 4.1 Comparison of Pre-test and Post-test scores across inclusive groups



Cohen's value deserves special attention. The variable d equal to 1.25 confirms the extremely high efficiency factor of VLs, exceeding the threshold value of 0.8. We can confidently describe that this technique, at least for small groups, not only helps, but qualitatively changes the educational process. Technology has not only adjusted the learning process but has radically changed the way the material is assimilated, not by dry facts, but by visual content.

All the necessary data about the analysis is shown in Table 4.3 to familiarize yourself with the estimates of the Jamovi program on which the corresponding manipulations were performed.

Table 4.3 Paired Samples T-Test results

Paired Samples T-Test

			Statistic	Df	P	Effect Size	
Pre_Test	Post_Test	Student's t	-4.68	16.0	<.001	Cohen's d	-1.13

Note. $H_a \mu_{Measure 1 - Measure 2} \neq 0$

The Shapiro-Wilk test confirmed the normality of the distribution of differences between Pre-Test and Post-Test, which indicates that the data corresponds to parametric assumptions. To study in more detail the nature of the identified changes, an analysis of the magnitude of the effect for each category of inclusion was carried out separately. Cohens's d was used as a measure of the effect, which allows us to determine which of the subgroups had the maximum effect. Since the size of the subgroups varied from 2 to 4 people, the values obtained should be interpreted within the framework of these samples, without generalizing to a wider population, since a small sample size may overestimate the magnitude of the effect.

Table 4.4 Paired Samples T-Test of students with Physical disabilities

Paired Samples T-Test

			Statistic	df	P	Effect Size	
Pre_Test	Post_Test	Student's t	-4.43	2.00	.047	Cohen's d	-2.56

Note. $H_a: \mu_{\text{Measure 1}} - \mu_{\text{Measure 2}} \neq 0$

The analysis of a group of students with physical disabilities confirms the high assistive value of VLs. According to the results of Table 4.4, the implementation of this methodology led to a noticeable increase in indicators before and after the tests. Cohen's score of 2.56 is key, since a value greater than 2 is an extremely high indicator in pedagogical statistics, which indicates a marked improvement in performance in this subgroup after the intervention.

Table 4.5 Paired Samples T-Test of students with Speech and Language impairments

Paired Samples T-Test

			Statistic	df	P	Effect Size	
Pre_Test	Post_Test	Student's t	-5.00	3.00	.015	Cohen's d	-2.50

Note. $H_a: \mu_{\text{Measure 1}} - \mu_{\text{Measure 2}} \neq 0$

Cohen's score of 2.50 indicates a large effect size, which indicates a marked improvement in performance in this subgroup after the intervention.

Table 4.6 Paired Samples T-Test of Students with Learning difficulties

Paired Samples T-Test

			Statistic	df	p	Effect Size	
Pre_Test	Post_Test	Student's t	0.00	1.00	1.000	Cohen's d	0.00

Note. $H_a: \mu_{\text{Measure 1}} - \mu_{\text{Measure 2}} \neq 0$

There were no statistically significant changes in this subgroup ($t = 0.00$, $p = 1.000$, Cohen's $d = 0.00$), indicating the absence of an intervention effect. However, due to the extremely small sample size ($n = 2$), this result does not allow us to draw generalizing conclusions about the effectiveness of the method for students with learning difficulties.

Table 4.7 Paired Samples T-Test of Students with ADHD

Paired Samples T-Test

			Statistic	df	P	Effect Size	
Pre_Test	Post_Test	Student's t	-2.32	3.00	.103	Cohen's d	-1.16

Note. $H_a: \mu_{\text{Measure 1}} - \mu_{\text{Measure 2}} \neq 0$

For the ADHD group, Cohen's value of 1.16 indicates that the technique has the potential to teach this category, but its effectiveness also varies greatly depending on the individual characteristics of concentration and focus on content in specific students.

Despite this, the value of $d=1.16$ is still high. This contradiction is explained by the small sample size of 4 people, which reduces the statistical power of the test, preventing it from reaching the significance level, despite the practically pronounced effect.

Table 4.8 Paired Samples T-Test of students with Sensory disabilities

Paired Samples T-Test

			statistic	Df	P	Effect Size	
Pre_Test	Post_Test	Student's t	-7.00	1.00	.090	Cohen's d	-4.95

Note. $H_a: \mu_{\text{Measure 1}} - \mu_{\text{Measure 2}} \neq 0$

There were no statistically significant changes in this subgroup ($t=-7.00$, $p=.090$), however, the Cohen effect of size 4.95 indicates an exceptionally large effect size. It should be noted that this result is an extremely small sample of only 2 people, because of which the Cohen value is statistically unstable and should be interpreted with extreme caution.

Table 4.9 Paired Samples T-Test of students with Development delays

Paired Samples T-Test

			Statistic	df	p	Effect Size	
Pre_Test	Post_Test	Student's t	-1.00	1.00	.500	Cohen's d	-0.707

Note. $H_a: \mu_{\text{Measure 1}} - \mu_{\text{Measure 2}} \neq 0$

For this category, a moderate Cohen effect size of 0.707 was recorded, which is a worthy result in the teaching environment. However, from the point of view of mathematical statistics, current data do not allow us to unequivocally prove or disprove the effectiveness of the methodology for this type of student due to the small sample size ($n=2$).

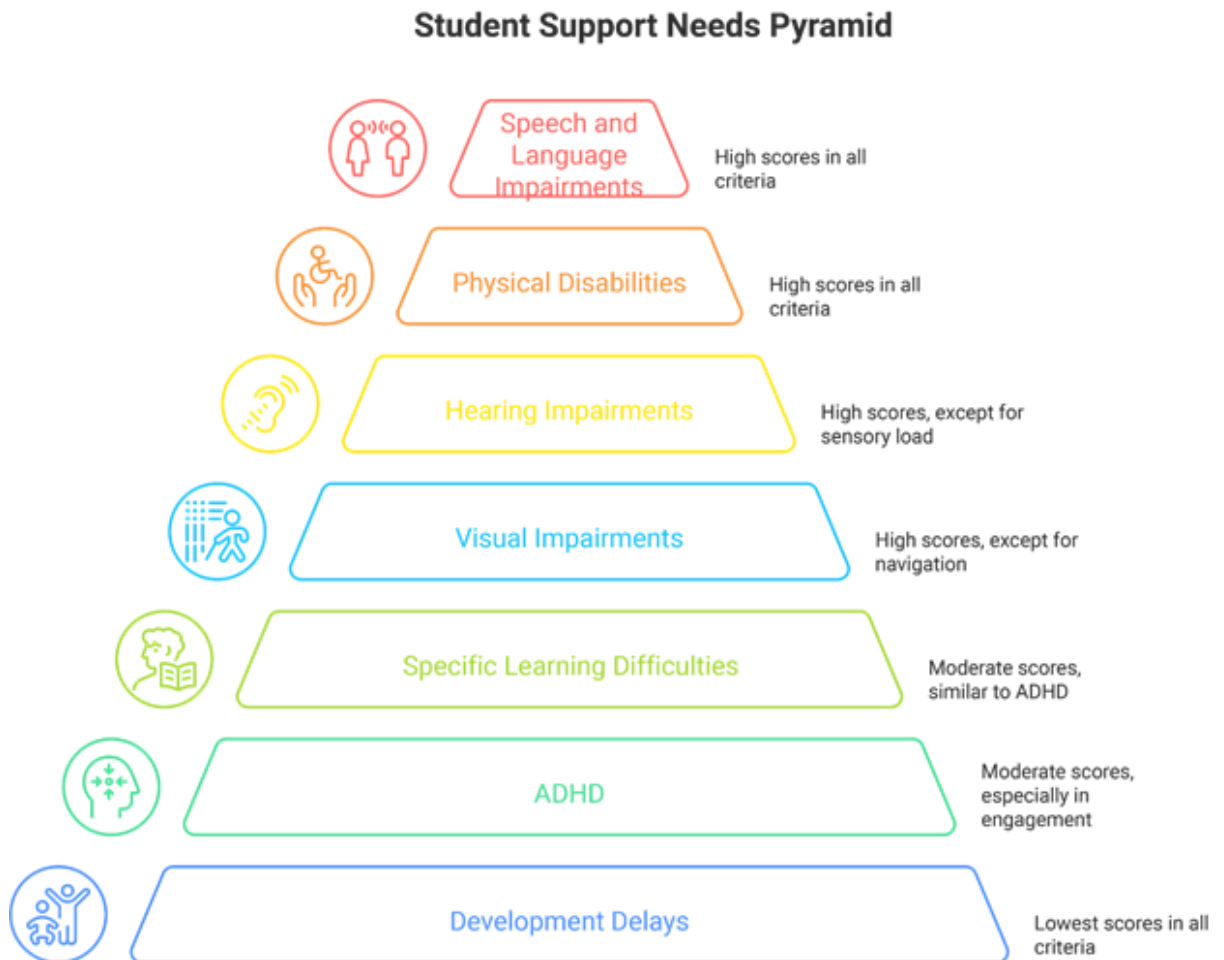
4.2 Results of Structured Observation

The data collected through structured observation provided an answer to the second research question “What cognitive and technical barriers do students with various forms of impairment have when using VCL?”. As was already emphasized earlier, in the second session the students should work without assistance, and their work was immediately observed and noted in the protocol. Help was offered only when the student stopped at one task for at least five minutes. In the observation methodology, criteria were prepared, such as understanding the performance of work, speed of navigation, sensory load, ability to independently experience chemistry without assistance, involvement in the subject. All these criteria for structured observation and assessment on scales from 1 to 5 are shown in Appendix 4 (pp. 82-83).

According to Appendix 4, the overall level of students' adaptation to the VL shows a high level. The average score on most assessment criteria varies between 4 and 5 points. The highest score was recorded in the “engagement in the subject” and “emotional comfort” sections (5.0), which indicates that psychological obstacles were overcome when studying chemistry.

The overall picture of accessibility is presented in the form of a pyramid in Figure 4.2, where all groups are arranged in a hierarchical order (from best to lowest results).

Figure 4.2 A pyramid for evaluating types of inclusion based on criteria



Students with physical disabilities demonstrate an extremely high degree of adaptability to the educational environment. High scores for understanding and navigation (5.0) confirm that the architecture of educational materials and the interface of the system are fully accessible to perception. Students feel emotionally comfortable, which contributes to productive learning. Despite this, during independent work and monitoring, the sensory load is at the 4.0 level. This may be due to technical difficulties in adapting assistive devices, which include VLs. Nevertheless, the overall dynamics are positive, and the group is effectively integrated into the learning process without significant cognitive barriers.

Students with speech and language impairments are absolute leaders in all criteria of statistical analysis. The 5.0 score on all counts proves that the presentation format for this type of inclusivity is perfectly balanced. The absence of a speech barrier in a digital or visual environment allowed them to reach their full potential. This is a reference group for which current teaching methods are the most effective. It can be concluded that the visual aspects in the presentation of information fully compensated for their special educational needs.

Students with ADHD are characterized by a specific and uneven pattern of engagement. Despite their interest in the subject (4.0), their indicators of understanding and emotional comfort remain at a moderate level (3.0). This illustrates that the classical structure of classes or the interface causes them rapid fatigue or stress. Difficulties with concentration directly affect the quality of learning and independent work. The low score for navigation has become a finishing factor, which is why the excess of elements or the lack of clear visual anchors disorient such students. Perhaps they require the introduction of additional game mechanics that do not distract them from their studies.

The group of students with specific learning difficulties shows stable but moderate performance in the form of 3 points according to most criteria. Understanding the material, navigation and control of sensory load are difficult for them, speaking of the cognitive barrier in the perception of complex structures. At the same time, the level of emotional comfort is rated above all criteria (4.0), which indicates a favorable atmosphere, but insufficient methodological support. To increase the effectiveness of training in this category, it is necessary to strengthen the hint system or use simpler constructions and provide more time to complete tasks.

The group with visual impairments demonstrates paradoxical results. This is justified by the fact that there is only one student in this group. This technique may be inaccurate for a large sample, but it provides an understanding that with maximum engagement and emotional comfort (5.0), they experience serious difficulties with sensory stress (3.0). This is a critical signal that the methods used may be overloaded

or insufficiently optimized to convey information about this type of inclusion. Navigation at the 4.0 level shows that orientation in space or interface requires excessive concentration and engagement from them.

Students with hearing impairments show very confident and even results. Maximum engagement confirms that high-level visual content can fully compensate for the lack of sound. Indicators for type, navigation, and independent work are kept at 4.0, which is a good indicator of the accessibility of the environment. This group does not experience serious problems with sensory overload, as the main focus is on visual aspects.

The latter category is the most vulnerable and requires a radical revision of the pedagogical approach. A group of students with developmental delays showed minimum scores (2.0) in many aspects of the criteria, indicating that the standard curriculum is not available to them. Students practically do not understand and do not know how to navigate the material without constant outside help. The average score for emotional comfort and sensory load of 3.0 points indicates that the environment does not cause aggression in them but also does not stimulate development. The current training format for them is formal and ineffective.

4.3 Feedback Results on Chemical Experience and Emotional Comfort

To the last research question: “How do students with SEN assess their chemical experience and emotional comfort when working in a virtual chemical environment? The answer was obtained using the structured interview method. The interview involved 17 participants with different types of inclusion. During the interview, students from the SEN shared their chemical experiences, experiences, and gave an assessment for the learning platform. The main purpose of the interview is to gain subjective experience of students with SEN. To keep the interview atmosphere comfortable and so that the children would not be afraid, the interview was completely anonymous.

Regarding the interview questions, we divided the “Experience of children with VCL” into four large topics: accessibility, understanding, comfort and motivation. To

ensure scientific reliability and anonymity, participants were assigned a unique code (for example, ADHD_01).

Availability: Most of the participants noted the convenience of the interface. However, it was revealed differently for each group. For example, for children with motor impairments, the VL allowed experiments to be carried out without much effort, and for children with ADHD, the VL was equipped with visual ergonomics, which made it possible to keep the student focused. The following quotes from children with SEN can be added to this section:

“It was easy for me to experiment in a virtual environment. With the help of the mouse, I was able to prepare solutions...”- (PD_01)

“When I was doing the experiment, I made a little mistake and my cup exploded! It was interesting! The explosion seemed to be realistic with the sound...” (ADHD_10)

“I liked the sounds when you stir the solutions and when the solution boils, there is a bubbling...” (HD_05)

“There are a lot of chemicals here and I used them to prepare different solutions. It was convenient to conduct an experiment, because when I made a mistake, I just deleted it and did it all over again...” (SL_05)

“In class, I usually ask my neighbor what's written on the blackboard. And here, on the monitor, I could zoom in. It's very convenient!” (VD_06)

“I liked that all the training is based on pictures and symbols. You don't need to read huge paragraphs or say something out loud.” (SL_04)

“I was able to zoom in on the monitor. It would be very convenient!” (VD_14).

Understanding: All the SEN groups responded naturally that the VCL helped them understand complex chemical topics. The participants of the DD noted that it was easier for them to perform experiments with the VCL environment than in a traditional lesson.:

“Everything was clear to me... It's hard in the book, but it's easy here” (DD_16)

There were also participants who noted the ease of performing chemical experiments due to the methodology or hints.:

“If I forgot the steps, I just opened them and looked at the methodology all the time” (LD_13)

“You don't need to read much there... A picture appeared and I did it.” (LD_12)

“It was like a quest, but everything was done without difficulties, because the instructions were clear.” (SD_04)

“It's difficult in the book, but it's easy here... I looked at the picture and did” (LD_13).

Comfort: During the second session, the students were already working independently, and many worked confidently on the platform, not afraid to make mistakes, thereby demonstrating emotional stability. The children performed chemical experiments without anxiety or fear of making mistakes. You can especially find out about this part by the following answers:

“I was comfortable working with VR... Sometimes I made mistakes, but I could fix it all” (SL_05)

“I really enjoyed working with a mouse, especially when I was working with test tubes rather than with real ones. It's usually scary to break appliances. And on the computer, I did everything confidently” (PD_03)

“Everything was clear on the computer. If I forgot something, I could think and no one would rush me.” (SL_07)

“I feel smart because I'm good at everything.” (DD_16)

“I'm usually afraid of breaking the lab equipment. Everything went smoothly and confidently on the computer” (PD_01).

Motivation and interest: The results of tests and observations, as shown by the analysis of the VCL, have a positive effect on the involvement of students with disabilities in the subject. And the interviewer was able to make an in-depth analysis of the participants' responses. All participants responded positively, and during the interview, everyone rated the VCL on a ten-point scale for interest. The high quantitative indicator (9.7) is confirmed by qualitative feedback from students who

compare the VCL with the gameplay. The following students were particularly positive about the platform:

“I poured the solutions myself and felt like I was in charge of the laboratory”
(PD_01)

“I was very interested when the liquid turned pink. I would like to play some more” (ADHD_08)

“I felt good... Sometimes I forgot that it was a lesson, because I perceived it as a game” (ADHD_10)

“We usually spend a lot of time in chemistry lessons... However, time flew by very quickly in such classes” (ADHD_09).

“Now I want to study chemistry in high school, because everything is easy here and I succeed” (SL_06)

“It was interesting to build big molecules from small atoms” (SL_05)

To create an overall picture of which topic was clearly expressed in the responses of each group, the most pronounced and identical responses were divided into groups, which are given in Appendix 5 (pp. 84-85).

According to Appendix 5, a detailed thematic analysis of each category of inclusion was carried out in order to identify the effectiveness of the VCL in the aspects of learning.

1) **Visual impairment:** The virtual environment provided an adaptive interface for students with visual impairments. The key advantage was the ability to customize visual interfaces individually. The student noted that traditional educational tools (blackboard or textbook) create a barrier that is eliminated in VR using a simple zoom function.

“...I was able to zoom in on the monitor. It would be very convenient!” (VD_14).

2) **Hearing disorders:** In addition to the visual component, audio feedback (gurgling, hissing reactions) also played a significant role as another means to verify the effectiveness of actions. This indicates the multimodality of the learning process, which helps to overcome sensory impairments.

“I liked the sounds when you stir the solutions and when the solution boils, there is a bubbling...” (HD_15)

3) **Attention deficit hyperactivity disorder:** Adolescents with ADHD demonstrated the greatest involvement among all other students. Under normal circumstances, their problem is that they quickly get tired of the monotony. A VL with gamification elements helped students enter the "flow" state.

“We usually spend a lot of time in chemistry classes.... However, time flew by very quickly in such classes” (ADHD_09).

The dynamism of the learning process and instant feedback help to retain attention and turn educational activities into an interactive game.

4) **Disorders of the musculoskeletal system.** For the aforementioned students, the VL has become a means of empowerment through physical activities. In real life, working with fragile materials and related substances is risky or impossible without the constant help of a laboratory technician. The digital space transforms complex precise movements into simple mouse commands.

“I'm usually afraid of breaking the lab equipment. Everything went smoothly and confidently on the computer” (PD_01).

This is crucial for gaining independence, because for the first time in their lives, students actively participated in experiments.

5) **Learning difficulties.** Students with SEN often experience anxiety before exams and a high cognitive load when working with detailed educational texts. In VL, they could make mistakes and imagine how the algorithm works.

“It's difficult in the book, but it's easy here.”... I looked at the picture and did” (LD_13).

The "undo" option and the ability to repeat the procedure without being criticized by the teacher reduce academic stress, allowing students to focus on understanding the logic of the chemical reaction.

6) **Speech disorders.** For this group of students, online learning turned out to be a way to reduce anxiety levels during oral communication. Interaction with the system is carried out using visual images, which makes it easier for them to learn knowledge without having communication problems. Information is obtained visually.

“I liked that all the training is based on pictures and symbols. You don't need to read huge paragraphs or say something out loud.” (SL_04)

7) **Delayed development.** The first important advantage of working with this target group is that it has allowed us to create a "success experience." The use of interactive prompts and visual cues at each stage (changing the color of the liquid, lighting effects) creates an effective system of prompts.

“I feel smart because I'm good at everything” (DD_16).

This helps to strengthen the self-esteem of children with developmental delays in a regular school setting, where it can be very low.

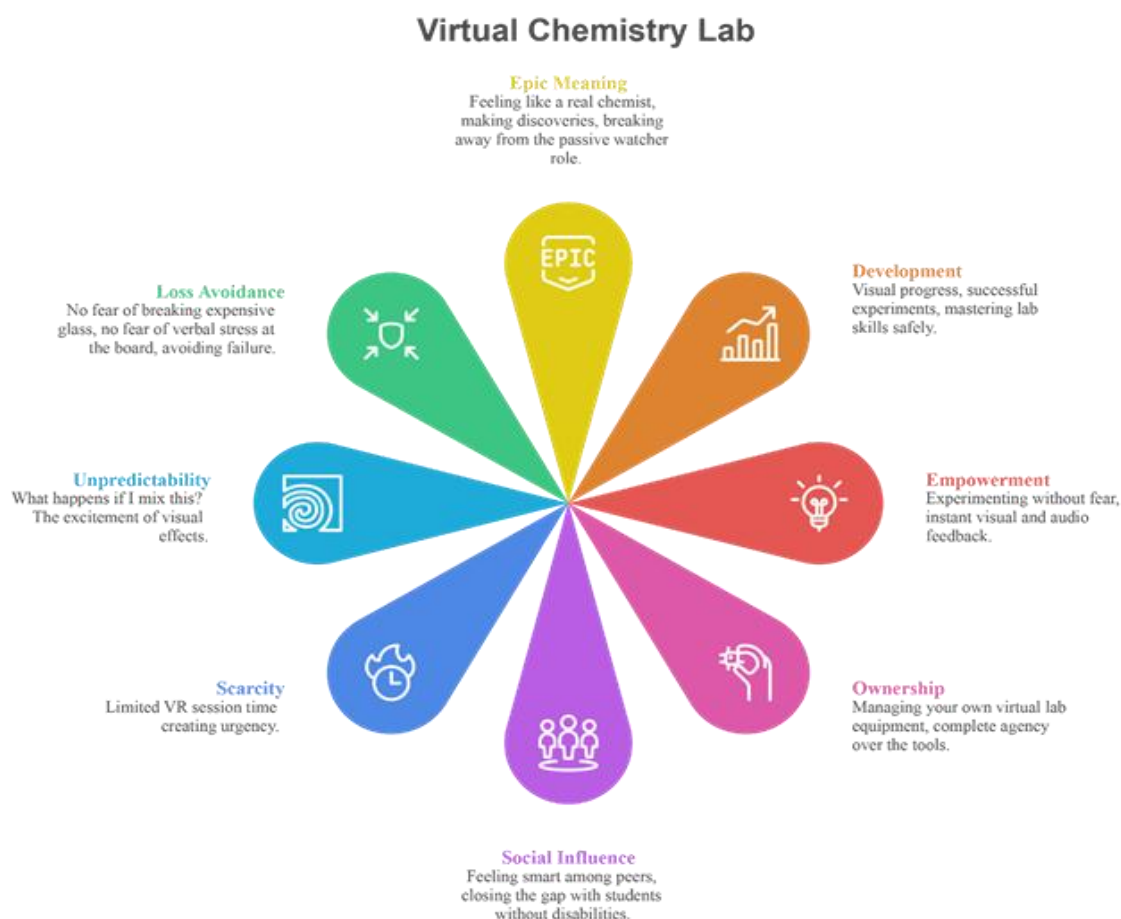
The Octalysis model (Chou, 2019) was used to summarize the qualitative information obtained during interviews with students (Fig. 4.3). This model divides student feedback into eight different motivational factors that describe the psychological attractiveness of the laboratory in a virtual environment.

Intrinsic motivation (epic meaning and sense of belonging): During the interview, a significant change in students' self-identification was revealed. The students moved from a state of passive academic activity to active scientific research since they managed to feel like real chemists and gain full control over virtual equipment.

Cognitive Support (Development and Empowerment): Visual progress can be observed, and the Delete and Repeat (instant feedback) feature can be used directly to meet the needs of students with ADHD and learning difficulties. This turns the chemical experiment into a safe sandbox for cognitive development.

Emotional safety (loss prevention): One of the common themes in the interview was the lack of fear of breaking glass. This factor serves as a psychological basis, eliminating stress and anxiety that usually interfere with learning in a high—risk physical laboratory - an effective filter.

Figure 4.3 Conclusions based on the results of the study: "Octalysis" models



Social and sensory engagement: The excitement of visual effects (curiosity) and the feeling of being smarter than your peers (social influence) confirm that VR is a social equalizer, and the gap between students with and without disabilities is narrowing.

The method shows that the success of a VL depends not only on the technology itself, but also on the ability to create an environment with a low level of stress and a high degree of engagement. She transforms an outdated chemical laboratory built on fear into a new immersion laboratory focused on curiosity.

DISCUSSION

The work has shown an extremely effective influence on the VCL. However, the methodology requires further development. It seems to me that the efficiency of work will increase when focusing on one inclusion group. This makes it possible to evaluate students among themselves and identify the positive and negative sides of the methodology. In my case, the distribution was not equal, the cognitive and physical limitations showed extreme diversity. In such circumstances, it is difficult to compare them and draw conclusions. However, this technique has created an overall picture of the impact of VCL on students with SEN. And it turned out that despite the limitations; scientific subjects can be fixed in practice using digital media no worse than traditional methods. Yes, not everyone had good results during the study, but if you take the general work, everyone has their own success.

5.1 Evaluating Learning Gains in an Inclusive Virtual Environment

5.1.1 Overall Efficiency of the Virtual Chemical Laboratory

It can be safely argued that the introduction of VCL as an interactive assistant had a statistically significant impact on students' academic performance. The average result for the entire sample increased from 4.71 to 6.88. The result, supported by a Paired Sample t-test ($t=-4.68$; $p<0.001$) and a good Cohen effect size ($d = -1.13$), indicates a real shift in academic achievement that cannot be explained by chance or regression to the mean.

The interpretation of David Rose (2001), who argues that the visual environment is gradually surpassing passive learning formats, is consistent with our conclusions. It is worth noting that the VCL is not a game in the usual sense, it is rather a web simulator with a simple interface that is aimed at beginners. However, this simplicity in the interface has become a major factor in efficiency. The students did not spend cognitive resources on mastering the complex interface but directed them directly to the study of processes.

The Shapiro-Wilk test confirmed the normality of the data distribution ($W=0.962$; $p=.669$). This ensures the correct application of the parametric criterion and

increases the reliability of the conclusions. Statistical conclusions make it clear that the observed effect is not a statistical error, but a real learning impact of the virtual environment on students with various types of disabilities.

5.1.2 Effectiveness by Student Groups

The overall positive picture is still not perfect, the effectiveness of the VCL turned out to be uneven. As expected earlier, it depends on the type of violation. Despite this, this unevenness proved to be the most valuable conclusion of the study (RQ1). This makes it clear that a universal tool that works for all types of inclusion is still a pedagogical utopia. This work provides factual confirmation of this statement.

The results of students with speech and language impairments showed powerful dynamics (pre: 5.0; post: 8.75; Cohen's $d = -2.50$; $p = .015$). A similar sharp jump was recorded in the group with physical disabilities (pre: 3.67; post: 6.33; Cohen's $d = -2.56$; $p = .047$). Take a look at the effect sizes. Both indicators break through the standard Cohen "big effect" threshold ($d > 0.8$). The practical significance of the experiment is obvious. The web simulator simply eliminates the barriers of a traditional laboratory. There is no physical unavailability of the devices. There is no communicative pressure from a public response. Observation fully confirms this logic. Both groups scored an absolute maximum (5.0) according to the criteria of "Understanding", "Engagement" and "Emotional comfort". It works perfectly.

A group of students with sensory impairments (hearing and vision) showed an abnormally large effect size (Cohen's $d = -4.95$). At the same time, the formal p-value turned out to be insignificant ($p = .090$). This is a classic statistical paradox. The reason is obvious, the small size of the subgroup ($n=2$). At the level of individual results, the increase is enormous. It is a gross statistical error to evaluate this result as "no effect" due to the formal p-value. Nevertheless, the direction requires strict verification on a wide sample. Theoretically, the result is completely consistent with the concept of universal design for learning (Universal Design for Learning, Ross D., 2001). The logic is simple. The simulator provides multiple channels of perception: visual, digital, interactive. This is critically important for students with sensory disabilities.

The ADHD group ($p = .103$; Cohen's $d = -1.16$) took an intermediate position in the study. The average score increased from 4.0 to 5.75. However, the threshold of statistical significance was not reached. The conclusion is obvious. The VCL here acts more as an assistive tool, rather than as a breakthrough technology for improving academic performance. The visual dynamics and instant feedback of the simulator effectively keep the students' attention. Fact. However, this factor alone does not ensure sustained academic progress. Without the integration of additional techniques and strict structural measures, software alone is not enough here.

The result of the study introduces an important thesis into the general scientific discussion. VCL is not a universal panacea. The platform requires a flexible, differentiated approach to pedagogical support for each specific category of inclusion.

5.2 Qualitative Analysis of Observations

Structured observation data does not simply duplicate quantitative reports. They reveal the internal mechanisms beyond the dry statistics. We assessed the interaction based on six basic criteria: understanding, navigation, sensory load, work autonomy, engagement, and emotional comfort. Such a complex provides the most objective picture of students' integration into the digital environment. The groups with peak academic results — students with physical disabilities and speech defects — produced the highest behavioral indicators. An absolute maximum of **5.0** points was recorded for most positions. It is noteworthy that the emotional comfort here has also reached its limit. This is directly related to the concept of the "affective filter" by S. Krashen (Krashen, S., 1992). The logic is simple: minimizing anxiety and increasing confidence are the basic triggers for learning. The VCL has created a so-called "result territory" for this category. This is a space where an inclusive student acts on an equal footing with his peers for the first time. Against this background, a group of students with mental retardation requires special analysis. Their scores were the lowest in the entire sample. Critical subsidence is recorded in the plane of understanding (2.0) and navigation (2.0). An important caveat: the root of the problem lies not in the plan of motivation. The emotional comfort score remained at 3.0 — the students did not

experience any obvious negativity. The problem lies precisely in the cognitive accessibility of the interface. The simulator, created without considering the specifics of the development delays, imposed excessive demands on the cognitive sphere. Interactive by itself is not a substitute for targeted pedagogical support. Qualitative observation has clearly fixed this barrier, which usually escapes with a bare quantitative calculation. The dynamics of the ADHD group are also indicative. With relatively low academic results, they demonstrated excellent engagement (4.0) and stable emotional comfort (3.0). The gap between engagement and final productivity is a key marker of the study. This answers the research question 2. VCL effectively solves the problem of attention retention. However, interest alone does not automatically translate into deep knowledge.

5.3 Motivation in Virtual Chemistry Labs: Interview-Driven Analysis via Octalysis

5.3.1 Results of the Thematic Analysis of the Interview

The thematic analysis of the interview allowed us to identify key semantic markers. During the coding of the responses, we recorded a clear focus on the following aspects: emotional safety, reduction of psychological barriers and communicative stress. The students also highlighted the growth of self-confidence. In terms of working with the interface, attention retention, engagement enhancement, and algorithm visualization codes dominate. A separate data set was formed by markers of scalability of the material, multisensory feedback, auditory simulation of processes, as well as minimization of verbal and cognitive load.

The revealed grid of codes proves the main thing. The effectiveness of the VCL is based not only on the visual appeal of the interface. The point is deeper. The platform can flexibly adapt to the specific physical and cognitive limitations of students. This is its main value.

The accessibility of the platform has become a central topic of discussion. This issue was most acute for students with visual impairments. Their responses are dominated by the markers "scalability of the material" and "technological autonomy".

Students openly stated severe perception difficulties in traditional lessons. In the digital environment, this problem disappears.

Our results verify the conclusions of the study by Sualo et al. (2014). The authors proved the positive effect of sound description and tactile feedback on respondents with sensory disabilities. In our experiment, a group of students with hearing impairments also highly appreciated "multisensory feedback" and "auditory simulation of processes." The contrast is obvious. In the classical laboratory, such students fall into passive observation because of their characteristics. In the VCL environment, they instantly turn into active subjects of activity. The method works.

Data analysis clearly demonstrates that for students with development delays and speech impairments, the dominance of visual algorithms over the text block is critically important. The traditional chemistry textbook, with its excess of verbalization, turns into a blind barrier. The VCL breaks this obstacle. The platform offers a direct path of intuitive understanding through symbols, drawings and interactive images. The result is obvious. The participants keep a hard focus on the essence of the chemical process. Cognitive resources are no longer spent on deciphering complex text instructions.

The central outcome of the interview is a strong connection between the accessibility of the platform and the emotional comfort of the students. The ability to make mistakes, promptly correct flaws, and repeat the experiment again works flawlessly. This directly reduces psychological barriers and guarantees emotional security. Minimizing stress and anxiety factors allows students to immerse themselves deeply in research. As a result, engagement and self—confidence increase dramatically.

In their work, Cooper et al. (2014) proved that in a virtual environment, people with musculoskeletal disorders fully participate in laboratory practices. This is achieved through accessible, responsive interfaces. Our experiment fully confirmed the authors' conclusions. For the group with motor impairments, the extreme simplification of physical activity (controlling one mouse) had a double effect. We have received not just a technical simplification of the task, but a powerful increase in emotional comfort.

Getting rid of the fear of breaking equipment or getting injured proves the main thing. The virtual educational environment performs the function of a "psychological prosthesis". It creates a safe zone for full-fledged chemical experiments.

5.3.2 Analysis via the Perspective of the Octalysis Framework

Using the Octalysis framework is fully justified since the virtual laboratory represents an interactive website simulation with well-defined gamification characteristics. One should point out the personal experience of the students that viewed the simulator as a game. As an example, can be mentioned statements made by ADHD_10 who states, "It felt good... Sometimes I did not even realize it was a class because I was having a blast". Another testimony that speaks in favor of the gamified platform is provided by ADHD_09 who says, "We usually sit in our chemistry classes for a long time... but in this one, time flies past us". This phenomenon is called the "Flow State" by Csikszentmihalyi (2014). A person gets involved in the process to such an extent that he simply loses all sense of time. In a regular class, this rarely happens with children with ADHD.

This means that the most important thing for our case is something called the "Epic Meaning" in theory. Students felt like they were engaged in studying science for the first time and they stopped feeling like passive witnesses. "I was really interested when the liquid turned pink. I would like to play again," said a student diagnosed with ADHD (ADHD_08). A student who usually finds it hard to concentrate voluntarily stated that he wanted to go on working. SL_06 argued that "Now I want to study chemistry like this! Everything is easy and I achieve results here."

In terms of the "Loss & Avoidance" trigger, it turned out to be the key component in Octalysis. The trigger appeared to be most prominent among the category of students who had some kind of physical impairments. A quotation from one of the interviews: "I am usually afraid of breaking something in the laboratory. But while working on the computer, it all went without a hitch." This statement reflects one of the major issues of inclusive education – fear of actual equipment, which cannot be

overcome using conventional teaching approaches. This problem can be solved at a structural level, rather than adapting individually.

"The Empowerment" aspect was revealed in the comments of several groups. One visually impaired student remarked: "In regular classes, I always ask my classmate about what's written on the board. But now, in this simulation, I can just zoom in to the screen. It's great!" It should be noted that the compensatory function in the interface was implemented in a natural way. Thus, the sound effects helped better understand the information. Quote: "I liked sounds of the mortar being stirred, and of the boiling process..." Conclusion: reduced verbosity contributes to effective communication and thinking.

"Unpredictability" appeared rather prominently in interviews conducted with the students' experiencing difficulties with learning. Excerpts from the interviews include "This is very complex in the book, but it is simple here; all I needed to do was to look at the drawing and solve it" and "It was exciting to form big molecules out of little atoms." Such markers are very significant considering the statistically insignificant test results demonstrated by the group. Unfortunately, during the limited time of the tests, this could not be translated into any achievement in academics. Such an outcome provides an independent finding which is valuable.

The aspects of "Ownership" and "Social Influence" turned out to be more vivid in the case of developmental disorders. "I am clever since I have good grades," a participant said. Such an observation opens one level that can hardly be seen with statistics alone. It refers to restoring self-respect that has been stifled due to a lack of adaptation. Sense of competence is one of the fundamental needs in self-determination theory (Vallerand, R. J., 2000). It is difficult to provide such a resource for students in need in a regular classroom setting. Its development during use of the simulator shows how profound the potential of this technological solution is. Moreover, its impact goes beyond just accumulating academic achievements. The analysis of this experience in terms of Octalysis only reinforces this idea.

VCL provides access to the most potent set of motivational means necessary for the creation of an inclusive atmosphere. The system acts in an all-round manner by eliminating the feeling of fear and nervousness altogether and fostering the feeling of belonging among learners. The simulator does not work as educational software but as a full-fledged mechanism that promotes social inclusion. And this is the primary objective of inclusive education.

CONCLUSION

Within the framework of this study, an important pedagogical task was solved. We have substantiated and experimentally verified the effectiveness of the implementation of the VCL as a learning tool. In the digital age, interactive simulation does not play the role of an assistive tool, but a necessary condition for ensuring equal access to education. Based on this, we draw three main conclusions.

The results of the comparative analysis of pre/post testing fully confirmed the hypothesis of a positive effect of VCL on the assimilation of chemical phenomena. Visual visualization of abstract concepts and direct interactive work with virtual devices and reagents provided a statistically significant increase in knowledge among the majority of participants. Digital educational tools effectively compensate for the cognitive barriers that inevitably arise for inclusive groups when working with traditional text materials. Thus, the method has proven its worth.

The high level of autonomy and psychological comfort of the students was also recorded during the structured observation. The hierarchical pyramid of accessibility developed in the framework of the analysis clearly reflects the distribution of technical and cognitive barriers depending on the specific type of inclusion. The experiment proved that the vast majority of participants can perform chemical experiments autonomously. The main condition is that the interface should provide step—by-step support and completely minimize the risk of physical error.

Thirdly, using qualitative interview analysis and the Octalysis framework, we have uncovered the internal mechanisms of the platform's success. We found that a triad of factors is critically important for launching a full-fledged cognitive process in students with SEN: psychological comfort, absolute safety, and adaptive game mechanics. During the interviews, the respondents made it clear to us that it was the lack of fear of real experience that allowed them to fully focus on the chemical essence of the experiment, rather than on their own physical or cognitive limitations. We have recorded the main result — the platform has successfully removed the mental barrier.

The practical significance of our work lies in the development of subject-specific methodological recommendations for chemistry teachers working in the field of inclusive education. Based on the results obtained, we have formulated three key rules:

1. The principle of "adaptive bridge". Before admission to real chemical experiments, students need to test the experiment in the VCL environment. This removes the primary barrier of fear.

2. Differentiation of constraints. When choosing the level of difficulty of tasks, the teacher must take into account the specifics of cognitive or physical impairments of a particular student.

3. System integration. The introduction of VCL into the curriculum on an ongoing basis guarantees stable academic progress without destructive pressure on the student's psycho-emotional state.

Despite the high heterogeneity of the sample (which included cognitive, sensory, and motor impairments), we fully achieved our goal and recreated a holistic picture of students' interaction with the SEN and the digital laboratory. At the same time, we clearly see a vector for further research. Applying our methodology in isolation for one specific nosology (for example, exclusively for visually impaired students) will allow us to obtain even deeper layers of data. The focus on homogeneous groups will ensure maximum statistical accuracy, detailed customization of the interface, and identification of hidden micro barriers. Our work has laid a solid foundation for this.

LIMITATIONS

Given that this study has proven to be extremely positive, it has several limitations that must be considered when interpreting data and modeling future stages of the virtual methodology implementation.

The main limitation is the relatively small sample of 17 students, since each inclusion category was represented by a small number of students, the information obtained should be considered as a pilot. The magnitude of the Cohen effect in some groups (for example, the group with sensory impairments $d=4.95$) is extremely high, which in conditions of a small sample may indicate the individual characteristics of specific students, rather than a universal pattern for the entire category.

Additionally, it is necessary to mention the difficulties in comparative analysis in relation to different categories of inclusion. As described earlier, the group was divided into 6 different categories that are fundamentally different from each other. Because of this, a fair and neutral analysis of the results between the groups is difficult.

In addition, the very novelty of the VCL as an assistive tool is one of the important limitations. Since the first VLs appeared only by the end of the 90s, there are currently no well-established criteria for evaluating their effectiveness. In this regard, the development of such criteria has become the primary task of this study. However, due to the fundamental differences between the types of specific limitations of participants, each of them requires a separate and unique assessment methodology.

The researcher's bias factor is also important. The predominance of optimistic estimates of the data increases the risk of subjective interpretation. Qualitative data, especially the emotional reactions of students, are inherently subject to ambiguous interpretation. The interpretation of such data largely depends on the subjective perception of the researcher, that is, me. My personal experience and attitudes may inadvertently affect the formulation of conclusions. To minimize this risk, the study used triangulation methods and repeated data verification.

RECOMMENDATIONS

The results of the study allow us to formulate a few recommendations for the implementation of web-based VLs in the inclusive education system. The transition from very expensive VR headsets to cost-effective interactive web interfaces opens up new opportunities for widespread adoption of this technique.

Inclusive education becomes more flexible when using a web platform instead of specialized equipment. In particular, we offer the development of desktop VR solutions that do not require high costs and have a minimal risk of VR syndrome. This will allow virtual workshops to be used in schools with limited budgets, and all groups of students with SEN will have equal opportunities to access high-quality education.

The most important thing to convey to teachers is that the virtual environment should be considered not as an example, but as a place for independent activity. Statistics on the "Ownership" factor show that it is extremely important that students with physical disabilities can perform actions in the web interface without the help of an assistant. The pedagogical approach should be aimed at developing independence: the teacher acts only as a facilitator, whose task is to provide the student with the opportunity to independently complete a course of chemical experiment.

In order to be able to work with groups of students with ADHD and learning difficulties, attention management tools must be included in the web platform. Such as a micro-achievement system to keep ADHD learners focused, a maximally simplified design with minimal visual noise to avoid overloading, identified during our experiment.

Monitoring academic performance while implementing innovative methods helps to avoid such cognitive distortions and unjustified optimism. Also, the evaluation of VL results should be based on long-term academic performance tracks, rather than one-time tests, which will help to cut off the influence of the novelty factor and obtain an objective picture of academic progress.

REFERENCES

- Abdurazova, P. A., Usenbay, A. U., & Aldanazarova, M. Sh. (2025). *Advancing inclusive education: The impact and potential of virtual laboratory simulations for students with disabilities in chemistry*. *Scientific Journal of Pedagogy and Economics*, 413(1), 5–22. ISSN 2518–1467
- Absattarova, A., Satilmis, H. Y., Raikhanova, D., & Bekenova, G. (2025). *Researching the user experience of students with special educational needs using virtual chemistry laboratories*. *Педагогика и Методы Обучения*, 4(73), 26–39. doi:10.47344/dqbm619
- Ali, N., Ullah, S., Rabbi, I., Javed, M., & Zen, K. (2014). *Multimodal virtual laboratory for the students' learning enhancement in chemistry education*. In *Proceedings of the International Conference of Recent Trends in Information and Communication Technology*. <https://ieeexplore.ieee.org/document/7008581>
- Ali, N., & Ullah, S. (2020). *Review to analyze and compare virtual chemistry laboratories for their use in education*. *Journal of Chemical Education*, 97(10), 3563–3574. <https://doi.org/10.1021/acs.jchemed.0c00185>
- Alhashem, F., & Alfaiakawi, A. (2023). *Technology-enhanced learning through virtual laboratories in chemistry education*. *Contemporary Educational Technology*, 15(4), Article ep474. <https://doi.org/10.30935/cedtech/13739>
- Anderson, T. (Ed.). (2008). *The theory and practice of online learning*. Athabasca University Press. <https://doi.org/10.15215/aupress/9781897425084.01>
- Babateen, H. M. (2011). *The role of virtual laboratories in science education*. In *Proceedings of the 5th International Conference on Distance Learning and Education, IPCSIT (Vol. 12)*. ISBN: 978-981-08-9121-3
- Baladogh, S. M., Elgamal, A. F., & Abas, H. A. (2017). *Virtual lab to develop achievement in electronic circuits for hearing-impaired students*. *Education and Information Technologies*, 22(5), 2071–2085. <https://doi.org/10.1007/s10639-016-9526-8>
- Banihashem, S. K., Farrokhnia, M., Badali, M., & Noroozi, O. (2022). *The impacts of constructivist learning design and learning analytics on students' engagement and self-regulation*. *Innovations in Education and Teaching International*, 59(4), 442–452. <https://doi.org/10.1080/14703297.2021.1890634>
- Barker, P., & Gossman, P. (2015). *Structured environments in virtual laboratories for cognitive and neurological accessibility*. *Education and Information Technologies*, 20(4), 747–758. <https://doi.org/10.1080/14703297.2021.1890634>

- Berezi, I. U. (2025). *Virtual learning environment: Redefining higher educational delivery for efficiency and accessibility*. *International Journal of Educational Management*, Rivers State University, 1(1), 451–467. <https://ijedm.com/index.php/ijedm/article/view/38>
- Chang, S. C., Hsu, T. C., & Jong, M. S. Y. (2020). *Integration of the peer assessment approach with a virtual reality design system for learning earth science*. *Computers & Education*, 146, Article 103758. <https://doi.org/10.1016/j.compedu.2019.103758>
- Chou, Y. K. (2019). *Actionable gamification: Beyond points, badges, and leaderboards*. Packt Publishing. ISBN: 978–1788837781
- Comarú, M. W., Lopes, R. M., Braga, L. A. M., Batista Mota, F., & Galvão, C. (2021). *A bibliometric and descriptive analysis of inclusive education in science education*. *Studies in Science Education*, 57(2), 241–263. <https://doi.org/10.1080/03057267.2020.1830239>
- Cooper, M., & Hedges, L. (2014). *Enhancing STEM accessibility: The role of technology in supporting students with physical impairments*. *Journal of STEM Education*, 15(3), 45–52. <https://jstem.org/jstem/index.php/JSTEM/article/view/1749>
- Csikszentmihalyi, M., Abuhamdeh, S., & Nakamura, J. (2014). *Flow*. In M. Csikszentmihalyi (Ed.), *Flow and the foundations of positive psychology: The collected works of Mihaly Csikszentmihalyi* (pp. 227–238). Springer. https://doi.org/10.1007/978-94-017-9088-8_15
- Dalgarno, B., Bishop, A. G., Adlong, W., & Bedgood, D. R., Jr. (2009). *Effectiveness of a virtual laboratory as a preparatory resource for distance education chemistry students*. *Computers & Education*, 53(3), 853–865. <https://doi.org/10.1016/j.compedu.2009.05.005>
- Darby-White, T., Wicker, S., & Diack, M. (2019). *Evaluating the effectiveness of virtual chemistry laboratory (VCL) in enhancing conceptual understanding: Using VCL as pre-laboratory assignment*. *Journal of Computers in Mathematics and Science Teaching*, 38(1), 31–48. <https://www.learntechlib.org/primary/j/JCMST/v/38/n/1/>
- Demchenko, I. I. (2015). *Children with special educational needs in inclusive primary school [Дети с особыми образовательными потребностями в инклюзивной начальной школе]*. *Концепт*, (8), 206–210. <https://e-koncept.ru/2015/75240.htm>
- Deriba, F. G., Saqr, M., & Tukiainen, M. (2024). *Assessment of accessibility in virtual laboratories: A systematic review*. *Frontiers in Education*, 9, Article 1351711. <https://doi.org/10.3389/feduc.2024.1351711>

- d'Ham, C., De Vries, E., Girault, I., & Marzin, P. (2004). Exploiting distance technology to foster experimental design as a neglected learning objective in labwork in chemistry. *Journal of Science Education and Technology*, 13(4), 425–434. <https://doi.org/10.1007/s10956-004-1467-7>
- Duarte, M., & Butz, B. P. (2001, October). The virtual laboratory for the disabled. In *Proceedings of the 31st Annual Frontiers in Education Conference: Impact on Engineering and Science Education* (Vol. 3, pp. S1C-23). IEEE. <https://doi.org/10.1109/FIE.2001.963899>
- Edwards, B. I., Bielawski, K. S., Prada, R., & Cheok, A. D. (2019). Haptic virtual reality and immersive learning for enhanced organic chemistry instruction. *Virtual Reality*, 23(4), 363–373. <https://doi.org/10.1007/s10055-018-0345-4>
- Elfakki, A. O., Sghaier, S., & Alotaibi, A. A. (2023). An efficient system based on experimental laboratory in 3D virtual environment for students with learning disabilities. *Electronics*, 12(4), Article 989. <https://doi.org/10.3390/electronics12040989>
- Elkhouly, M. (2021). Perceptions of undergraduate students, lecturers, and lab assistants towards the use of online laboratory in science education during COVID-19 pandemic [Unpublished manuscript].
- Ghergulescu, I., Lynch, T., Bratu, M., Moldovan, A., Muntean, C. H., & Muntean, G. M. (2018). STEM education with atomic structure virtual lab for learners with special education needs. In *EDULEARN18 Proceedings* (pp. 8747–8752). IATED. <https://doi.org/10.21125/edulearn.2018.2095>
- Girmay, S., Yliniemi, K., Nieminen, M., Vilhunen, A., & Karttunen, A. J. (2026). Universal Design for Learning framework enhances learning experience in web-based virtual laboratories. *Journal of Chemical Education*, 103(3), 1182–1194. <https://doi.org/10.1021/acs.jchemed.5c01687>
- Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, 8(1), 1–32. <https://doi.org/10.1007/s40692-020-00169-2>
- Hodkinson, A. (2010). Inclusive and special education in the English educational system: Historical perspectives, recent developments and future challenges. *British Journal of Special Education*, 37(2), 65–73. <https://doi.org/10.1111/j.1467-8578.2010.00462.x>
- Hoole, D., & Sithambaresan, M. (2003). Analytical chemistry labs with kits and CD-based instructions as teaching aids for distance learning. *Journal of Chemical Education*, 80(11), 1308. <https://doi.org/10.1021/ed080p1308>

- Hofstein, A., & Lunetta, V. N. (2004). *The laboratory in science education: Foundations for the twenty-first century*. *Science Education*, 88(1), 28–54. <https://doi.org/10.1002/sce.10106>
- Humphrey, N., & Lewis, S. (2008). "Make me normal": The views and experiences of pupils on the autistic spectrum in mainstream secondary schools. *Autism*, 12(1), 23–46. <https://doi.org/10.1177/1362361307085267>
- Jeannis, H., Joseph, J., Goldberg, M., Seelman, K., Schmeler, M., & Cooper, R. A. (2018). Full-participation of students with physical disabilities in science and engineering laboratories. *Disability and Rehabilitation: Assistive Technology*, 13(2), 186–193. <https://doi.org/10.1080/17483107.2017.1297857>
- Jeannis, H., Goldberg, M., Seelman, K., Schmeler, M., & Cooper, R. A. (2020). Barriers and facilitators to students with physical disabilities' participation in academic laboratory spaces. *Disability and Rehabilitation: Assistive Technology*, 15(1), 59–65. <https://doi.org/10.1080/17483107.2018.1534251>
- Jensen, N., Seipel, S., von Voigt, G., Raasch, S., Olbrich, S., & Nejd, W. (2004). Development of a virtual laboratory system for science education and the study of collaborative action. In *Proceedings of EdMedia + Innovate Learning* (pp. 2148–2153). Association for the Advancement of Computing in Education (AACE). ISBN: 1-880094-52-5
- Kay, R., Goulding, H., & Li, J. (2018). Assessing the impact of a virtual lab in an allied health program. *Journal of Allied Health*, 47(1), 45–50. <https://pubmed.ncbi.nlm.nih.gov/29504019/>
- Kurbanoglu, N., & Akin, A. (2010). The relationships between university students' chemistry laboratory anxiety, attitudes, and self-efficacy beliefs. *Australian Journal of Teacher Education*, 35(8), 48–59. <https://doi.org/10.14221/ajte.2010v35n8.4>
- Krashen, S. (1992). The input hypothesis: An update. In J. E. Alatis (Ed.), *Linguistics and language pedagogy: The state of the art* (pp. 409–431). Georgetown University Press. ISBN: 978-0-87840-247-1
- Lindsay, G. (2003). Inclusive education: A critical perspective. *British Journal of Special Education*, 30(1), 3–12. <https://doi.org/10.1111/1467-8578.00240>
- Lindsay, G. (2007). Educational psychology and the effectiveness of inclusive education/mainstreaming. *British Journal of Educational Psychology*, 77(1), 1–24. <https://doi.org/10.1348/000709906X156881>
- Liu, C. C., Wen, C. T., Chang, H. Y., Chang, M. H., Lai, P. H., Fan Chiang, S. H., & Hwang, F. K. (2022). Augmenting the effect of virtual labs with "teacher demonstration" and "student critique" instructional designs to scaffold the

- development of scientific literacy. *Instructional Science*, 50(2), 303–333. <https://doi.org/10.1007/s11251-021-09563-6>
- Lynch, T., & Ghergulescu, I. (2017). Review of virtual labs as the emerging technologies for teaching STEM subjects. In *INTED2017 Proceedings* (pp. 6082–6091). IATED. <https://doi.org/10.21125/inted.2017.1415>
- Mamluk-Naaman, R. (2024). Diversity and inclusion in science education. Why? A literature review. *CEPS Journal*, 14(1), 13–31. <https://doi.org/10.26529/cepsj.1631>
- Ministry of Education of the Republic of Kazakhstan. (2022). *Pravila otsenki osobykh obrazovatel'nykh potrebnosti* [Rules for the assessment of special educational needs] (Order No. 4, 12 January 2022, Reg. No. 26618). <https://adilet.zan.kz/rus/docs/V2200026618>
- Moriña, A. (2019). Inclusive education in higher education: Challenges and opportunities. *European Journal of Special Needs Education*, 34(1), 3–17. <https://doi.org/10.1080/08856257.2018.1542352>
- Motejlek, J., & Alpay, E. (2019). A taxonomy for virtual and augmented reality in education. *arXiv*. <https://doi.org/10.48550/arXiv.1906.12051>
- Nakhleh, M. B., & Krajcik, J. S. (1994). Influence of levels of information as presented by different technologies on students' understanding of acid, base, and pH concepts. *Journal of Research in Science Teaching*, 31(10), 1077–1096. <https://doi.org/10.1002/tea.3660311004>
- Nsabayezu, E., Iyamuremye, A., Urengejeho, V., Mukiza, J., Ukobizaba, F., Mboniyirivuze, A., & Kwitonda, J. D. D. (2022). Computer-based learning to enhance chemistry instruction in the inclusive classroom: Teachers' and students' perceptions. *Education and Information Technologies*, 27(8), 11267–11284. <https://doi.org/10.1007/s10639-022-11082-9>
- Rombo, J. L. (2006). Inclusive education: Policies, teachers' attitudes and perspectives. *Contemporary PNG Studies*, 5, 29–44. <https://go.gale.com/ps/anonymous?id=GALE%7CA179978526>
- Rose, D. (2001). Universal design for learning. *Journal of Special Education Technology*, 16(4), 64–67. <https://doi.org/10.1177/016264340101600407>
- Rutten, N., Van Joolingen, W. R., & Van Der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, 58(1), 136–153. <https://doi.org/10.1016/j.compedu.2011.07.017>
- Shudayfat, E., Moldoveanu, F., Moldoveanu, A., & Dragos, B. (2012, October). A 3D virtual learning environment for teaching chemistry in high school. In *Annals of*

DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium (Vol. 23, No. 1, pp. 2304–1382). ISBN: 978-3-901509-84-1

- Sison, A. J. R. N., Bautista, J. M., Javier, J. L., Delmonte, R. J. B., & Cudera, R. B. (2024). Development and acceptability of virtual laboratory in learning systematics. *ASEAN Journal of Educational Research and Technology*, 3(1), 9–26. <https://doi.org/10.24191/ajert.v3i1.24576>
- Supalo, C., Mallouk, T., & Amorosi, C. (2014). A tactile and auditory approach to teaching labs. *Journal of Chemical Education*, 91(1), 190–194. <https://doi.org/10.1021/ed3008425>
- Thompson, S. E., Bourke, S. A., Callow, J. N., & Hipsey, M. R. (2022). Prioritizing engagement of a diverse student cohort in online hydrology learning at the University of Western Australia. *Frontiers in Education*, 7, Article 907801. <https://doi.org/10.3389/feduc.2022.907801>
- Ural, E. (2016). The effect of guided-inquiry laboratory experiments on science education students' chemistry laboratory attitudes, anxiety and achievement. *Journal of Education and Training Studies*, 4(4), 217–227. <https://doi.org/10.11114/jets.v4i4.1395>
- Vallerand, R. J. (2000). Deci and Ryan's self-determination theory: A view from the hierarchical model of intrinsic and extrinsic motivation. *Psychological Inquiry*, 11(4), 312–318. https://doi.org/10.1207/S15327965PLI1104_05
- Webb, M. E. (2005). Affordances of ICT in science learning: Implications for an integrated pedagogy. *International Journal of Science Education*, 27(6), 705–735. <https://doi.org/10.1080/09500690500038520>
- Wolski, R., & Jagodziński, P. (2019). Virtual laboratory—Using a hand movement recognition system to improve the quality of chemical education. *British Journal of Educational Technology*, 50(1), 218–231. <https://doi.org/10.1111/bjet.12563>
- Yang, Q. F., Lin, H., Hwang, G. J., Su, P. Y., & Zhao, J. H. (2024). An exploration-based SVVR approach to promote students' chemistry learning effectiveness. *Interactive Learning Environments*, 32(5), 2003–2027. <https://doi.org/10.1080/10494820.2022.2135106>

APPENDICES

Appendix 1

Expert agreement on interview questions based on the Absattarova approach (2025)

Experts	Quest 1	Quest 2	Quest 3	Quest 4	Quest 5	Quest 6
Expert 1	4.00	3.80	3.80	3.70	3.70	3.50
Expert 2	4.00	3.80	4.00	3.80	3.80	3.60
Expert 3	3.70	3.70	3.50	3.70	3.50	3.70
Expert 4	3.80	3.70	3.80	3.70	3.50	3.50
Expert 5	4.00	3.70	3.70	3.50	3.50	3.30

Validity of the 6th grade Pre- test questions

Ranks	
-	Mean Rank
Question_1	4,88
Question_2	3,25
Question_3	3,63
Question_4	1,75
Question_5	1,50

Test Statistics	
N	4
Kendall's W ^a	,853
Chi-Square	13,644
Df	4
Asymp. Sig.	,009
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,951	5

Validity of the 6th grade Post-test questions

Ranks	
-	Mean Rank
Question_1	4,50
Question_2	4,50
Question_3	2,63
Question_4	2,38
Question_5	1,00

Test Statistics	
N	4
Kendall's W ^a	,915
Chi-Square	14,633
Df	4
Asymp. Sig.	,006
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,812	5

Validity of the 7th grade Pre-test questions

Ranks	
-	Mean Rank
Question_1	4,25
Question_2	3,13
Question_3	1,25
Question_4	4,13
Question_5	2,25

Test Statistics	
N	4
Kendall's W ^a	,729
Chi-Square	11,662
Df	4
Asymp. Sig.	,020
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,930	5

Validity of the 7th grade Post-test questions

Ranks	
-	Mean Rank
Question_1	4,63
Question_2	3,88
Question_3	2,38
Question_4	3,00
Question_5	1,13

Test Statistics	
N	4
Kendall's W ^a	,824
Chi-Square	13,183
df	4
Asymp. Sig.	,010
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,819	5

Validity of the 8th grade Pre-test questions

Ranks	
-	Mean Rank
Question_1	4,25
Question_2	3,88
Question_3	1,38
Question_4	2,38
Question_5	3,13

Test Statistics	
N	4
Kendall's W ^a	,705
Chi-Square	11,279
df	4
Asymp. Sig.	,024
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,890	5

Validity of the 8th grade Post-test questions

Ranks	
-	Mean Rank
Question_1	4,25
Question_2	3,50
Question_3	1,13
Question_4	3,88
Question_5	2,25

Test Statistics	
N	4
Kendall's W ^a	,807
Chi-Square	12,909
Df	4
Asymp. Sig.	,012
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0

Reliability Statistics	
Cronbach's Alpha	N of Items
,910	5

Validity of the 9th grade Pre-test questions

Ranks	
-	Mean Rank
Question_1	3,50
Question_2	4,88
Question_3	1,13
Question_4	2,50
Question_5	3,00

Test Statistics	
N	4
Kendall's W ^a	,886
Chi-Square	14,176
Df	4
Asymp. Sig.	,007
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,931	5

Validity of the 9th grade Post-test questions

Ranks	
-	Mean Rank
Question_1	4,25
Question_2	2,50
Question_3	2,25
Question_4	4,50
Question_5	1,50

Test Statistics	
N	4
Kendall's W ^a	,753
Chi-Square	12,055
Df	4
Asymp. Sig.	,017
<i>a. Kendall's Coefficient of Concordance</i>	

Case Processing Summary			
-		N	%
Cases	Valid	4	100,0
	Excluded ^a	0	,0
	Total	4	100,0
<i>a. Listwise deletion based on all variables in the procedure.</i>			

Reliability Statistics	
Cronbach's Alpha	N of Items
,938	5

Students	Types of inclusivity	Pre-test	Post-test
Student 1	Students with physical disabilities	5	7
Student 2	Students with physical disabilities	4	6
Student 3	Students with physical disabilities	2	6
Student 4	Students with speech and language impairments	5	10
Student 5	Students with speech and language impairments	6	8
Student 6	Students with speech and language impairments	4	9
Student 7	Students with speech and language impairments	5	8
Student 8	Students with ADHD (Attention-Deficit/Hyperactivity Disorder)	5	7
Student 9	Students with ADHD (Attention-Deficit/Hyperactivity Disorder)	4	4
Student 10	Students with ADHD (Attention-Deficit/Hyperactivity Disorder)	3	6

Student 11	Students with ADHD (Attention-Deficit/Hyperactivity Disorder)	5	6
Student 12	Students with specific learning difficulties	8	6
Student 13	Students with specific learning difficulties	5	6
Student 14	Students with visual impairments	6	10
Student 15	Students with hearing impairments	5	8
Student 16	Students with Development delays	4	5
Student 17	Students with Development delays	4	4

Assessment of the work of students with SEN in accordance with the criteria of structured observation

<i>Criteria</i>	<i>Students with physical disabilities</i>	<i>Students with speech and language impairments</i>	<i>Students with ADHD (Attention-Deficit/Hyperactivity Disorder)</i>	<i>Students with specific learning difficulties</i>	<i>Students with visual impairments</i>	<i>Students with hearing impairments</i>	<i>Students with Development delays</i>
Understanding	5.0	5.0	3.0	3.0	5.0	4.0	2.0
Navigation	5.0	5.0	3.0	3.0	4.0	4.0	2.0
Sensory load	4.0	5.0	3.0	3.0	3.0	4.0	3.0
Independent work	4.0	5.0	3.0	3.0	4.0	4.0	2.0
Engagement with the subject	5.0	5.0	4.0	3.0	5.0	5.0	2.0

Emotional comfort	5.0	5.0	3.0	4.0	5.0	4.0	3.0
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The scale of autonomy:

1 - there are no manifestations of the criterion. The student did not understand how to work with the VCL and was afraid to act. The teacher performs a chemistry experiment with the student from beginning to end.

2 - entry level. The student makes attempts but makes many mistakes. He needs to be prompted step by step for each step of the work.

3 - the average level. The student understands the essence of the VCL but gets stuck on difficult points. He needs more hints.

4 - confident level. The student almost performs the tasks himself. The teacher gives a couple of hints about technical errors.

5 - complete independence. The student performs the chemical experiment from beginning to end by himself without outside help.

The scale of engagement, emotional comfort and sensory load:

1 - severe anxiety/lack of interest/overload; 2 - visible anxiety/automatic execution/high degree of stress; 3 - calm state/ passive participation/ moderate stress; 4 - confidence/active participation/ low stress; 5 - high feelings of comfort/ high research interest/ minimal sensory stress.

Topic	Inclusion Group	Quote	That it proves (Code)
Comfort	<i>Students with physical disabilities</i>	<i>“I'm usually afraid of breaking the lab equipment. Everything went smoothly and confidently on the computer”</i>	Reduction of psychological barriers, emotional safety
Availability	<i>Students with visual impairments</i>	<i>“In class, I usually ask my neighbor what's written on the blackboard. And here, on the monitor, I could zoom in. It's very convenient!”</i>	Scalability of the material, technological autonomy
Availability	<i>Students with hearing impairments</i>	<i>“I liked the sounds when you stir the solutions and when the solution boils, there is a bubbling...”</i>	Multisensory feedback, auditory simulation of processes
Motivation and interest	<i>Students with ADHD (Attention-Deficit/Hyperactivity Disorder)</i>	<i>“...However, time flew by very quickly in such classes.”</i>	Attention retention, increased engagement

Availability	<i>Students with speech and language impairments</i>	<i>"I liked that all the training is based on pictures and symbols. You don't need to read huge paragraphs or say something out loud."</i>	Minimization of verbal load, reduction of communicative stress
Comfort	<i>Students with Development delays</i>	<i>"I feel smart because I'm doing well"</i>	Self-confidence, increased engagement
Understanding	<i>Students with specific learning difficulties</i>	<i>"It's difficult in the book, but it's easy here."... I looked at the picture and did"</i>	Cognitive load reduction, algorithm visualization