Systematic Review of Virtual Reality Applications for Teaching Chemistry Using Meta Oculus Quest 2 and Testing of a Selected Application

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Research shows that virtual reality holds significant potential to help students improve their skills and knowledge. In our investigation, we systematically examined possible applications for teaching chemistry using the Meta Oculus Quest 2 glasses based on selected criteria (cost, content, possibility of conducting virtual experiments, added value of VR technology). This was followed by a case study in which we tested the most suitable application, *The VR Chemistry Lab*, with six students from a general secondary school. The results showed students had a stronger interest in learning chemistry through the VR and revealed their awkwardness while working in the virtual lab, which calls for manual skills and techniques considerably different from work in a real lab. In the discussion, the urgent need for a more comprehensive approach to developing applications for virtual chemistry labs for teaching is stressed, for which collaboration between computer experts, chemists and chemistry educators is essential.

Keywords:
chemistry,
education,
technology,
virtual laboratory,
virtual reality

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Sistematični pregled in preizkus kemijske izobraževalne aplikacije za virtualno resničnost z VR očali Meta Oculus Quest 2

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Ključne besede:
izobraževanje,
kemija,
tehnologija,
virtualni laboratorij,
virtualna resničnost

Raziskave kažejo, da ima virtualna resničnost velik potencial kot pomoč učencem pri izboljšanju njihovih veščin in znanja. Pri raziskovanju smo sistematično pregledali možne aplikacije za poučevanje kemije z očali Meta Oculus Quest 2 po izbranih kriterijih (strošek, vsebina, možnost izvajanja virtualnega eksperimenta, dodana vrednost VR tehnologije). Sledila je študija primera, pri kateri smo preizkusili izbrano najprimernejšo aplikacijo The VR Chemistry Lab s šestimi dijaki splošne gimnazije. Rezultati so pokazali večje zanimanje dijakov za učenje kemije z VR in njihovo nespretnost pri virtualnem laboratorijskem delu, ki je v ročnih spretnostih in tehnikah bistveno drugačno od realnega laboratorijskega dela. V diskusiji izpostavljamo nujno potrebo po celovitejšem pristopu pri razvoju aplikacij virtualnih kemijskih laboratorijih, namenjenih izobraževanju, kjer je poleg računalniških strokovnjakov potrebno sodelovanje kemijskih strokovnjakov in didaktikov kemije.

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1 Introduction

In recent decades, modern technologies have become an indispensable part of day-to-day lives. They have a substantial impact on our work, leisure time, social interactions, acquisition of information, and use of tools in both the workplace and education. The SARS-CoV-2 pandemic has also contributed to this, requiring the rapid adaptation of technologies for remote learning to maintain the normal learning schedule and achieve educational goals. Significant progress has been made in implementing innovative pedagogical approaches, providing an opportunity to explore innovative open educational platforms, practices and resources (Madhuri and Prakash Goteti, 2022). Education without modern technologies is nowadays practically unimaginable.

In today's education, 21st-century competencies, also known as soft skills, are vital. These include critical thinking and problem-solving, creativity and innovation, communication skills and collaboration abilities. To enable students to attain these competencies, they must be provided with an innovative learning environment that includes the use of ICT tools, the opportunity to create ICT content, and access to information. Systematic and appropriate use of ICT promotes greater flexibility, individualisation and personalisation (Štemberger et al., 2022). Ferk Savec (2015) emphasises the term "knowledge for teaching with ICT" – TPACK (Technological Pedagogical Content Knowledge), which describes the knowledge base needed for integrating technology into education (Ferk Savec, 2015). Learning and teaching in the digital society can be supported by artificial intelligence, learning analytics, mobile learning, microlearning, gamification, simulations (Bregar et al., 2020) and virtual reality, with the latter becoming ever more prevalent (Wijayanti and Ikhsan, 2019).

Virtual reality (VR) refers to a computer-generated simulation in which a person can move around in an artificial three-dimensional environment and interact with the help of special electronic devices. In this simulated artificial environment, the user can explore the space around them, use objects, and perform various activities (Bregar et al., 2020). Users can manipulate computer-generated objects with devices such as haptic devices (Ardiny and Khanmirza, 2018), with one example being virtual reality (VR) glasses. Immersion in virtual space (IVR) is a central feature of the learning experience in VR (Bregar et al., 2020). We are also familiar with augmented reality (AR) whereby computer-programmed information and elements are connected to the real world (Ardiny and Khanmirza, 2018).

One of the main goals of introducing VR technology in classrooms is to personalise and thereby add to the efficiency of the learning process. Teachers can create content tailored to individual needs, accommodate various cognitive levels, make specific adjustments, and provide feedback. VR can be effectively used as a teaching tool in various areas like interactive and collaborative learning, virtual classrooms, practical training, and virtual excursions (Bregar et al., 2020). Through virtual excursions, students can explore historical sites, distant places, museums, other countries, and different industrial processes, productions and factories that are otherwise inaccessible (Muz and Yüce, 2023). Teachers involved in a study (Yıldırım et al., 2020), whose purpose was to determine teachers' opinions on virtual reality after they had applied VR for 2 months in their classrooms, suggested the following aspects for integrating VR into the classroom: Review of the learning objectives and content for VR; adaptation of teaching activities; consideration of learning styles; preparation of students for VR; collaboration with experts; reflection on the technical challenges; and evaluation of the learning experience in VR.

A key advantage over conventional teaching methods is that VR allows users to experience content that would be difficult, if not impossible, to demonstrate or describe using traditional methods (Yoo and Brownlee, 2020). VR enables the viewing of 3D models, virtual manipulation of objects, and understanding of invisible phenomena (Ardiny and Khanmirza, 2018). Further, VR technology is useful in education for visualising complex spatial representations and enhancing understanding of abstract concepts, processes and phenomena related to the submicroscopic world. Research (Frevert and Fuccia, 2021) that assessed students' understanding of the chemical aspects of the coronavirus (SARS-CoV-2) as content using the VR application Nanome showed that VR helped students understand the structure and biochemical functionality of the coronavirus. Modern topics were linked in this way with technologies and the students' chemical knowledge and digital competencies were promoted. Interviews with the students revealed they felt motivated in the digital learning environments and had acquired more content knowledge (Frevert and Fuccia, 2021). Sarıoğlu and Girgin (2020, in Muz and Yüce, 2023) established that VR technology positively influences achievements and attitudes to science and technology subjects. Conducted between 2013 and 2022, research indexed in SCOPUS, ERIC and Web of Science was analysed in a study by Muz and Yüce (2023) in terms of predefined criteria like publication year, research designs, target groups, field, data collection tool, data analysis method and main results. A review of 23 studies found that use of VR in education contributes to academic achievement, motivation, efficiency, sustained learning, attitude to teaching, positive thinking, critical thinking, and collaboration. The results also suggest that VR is more effective when used as an alternative teaching method compared to traditional teaching methods (Muz and Yüce, 2023).

Despite numerous advantages, the use of VR glasses in education brings some challenges. One of them is the lack of affordable hardware and the development of applications that are suitable for use. As this technology is still under development, technical issues arise, such as the need for powerful computers and appropriate equipment (Bregar et al., 2020). There are also limited resources and funds available to purchase and maintain VR equipment. Some research also mentions the restricted opportunities to integrate VR technology into the curriculum and conduct learning activities within a limited time frame (Yıldırım et al., 2020). Users of VR glasses may experience side effects such as nausea, dizziness, headache, eye fatigue (LaValle, 2020) and disorientation, typically caused by a mismatch between visual perception and the sense of movement (Ardiny and Khanmirza, 2018). Head-mounted displays (HMDs) are relatively heavy, potentially causing user fatigue over an extended period (Ardiny and Khanmirza, 2018).

1.1 Virtual reality in chemistry education

A notable benefit of using VR glasses in chemistry lessons is the ability to conduct laboratory experiments in a virtual environment, which enhances the hands-on learning experience. In addition, VR goggles enable visually appealing and realistic simulations of molecules, chemical reactions, and abstract concepts, thereby contributing to a better understanding and visualisation of chemistry (Oprčkal and Hriberšek, 2023). VR is particularly beneficial for chemistry and other sciences because it provides clear visual and spatial representations of complex concepts. The ability to visualise and concretise abstract concepts is an important advantage of teaching science in VR (Hu-Au and Okita, 2021). Sakamoto (2018) states that use of VR technology boosts interest and motivation for learning natural science subjects and can help with better understanding and visualisation of scientific concepts

(Sakamoto, 2018). In another study (Lu, Xu and Zhu, 2021), the focus was on the possibility of involving students with mobility impairments interested in experimental chemistry. Most chemistry experiments are inaccessible to students with mobility impairments, e.g., students in wheelchairs. With VR glasses and the use of chemistry applications, they can become accessible for them. Despite the advantages, experts note that currently there is a lack of suitable content aligned with the curriculum or suitable VR applications for chemistry lessons (Dinther et al., 2023).

Many schools lack adequate equipment for laboratory work, have expired chemicals or an inadequate laboratory inventory. This problem can be solved by technology – virtual labs (Suleman et al., 2019). A virtual laboratory is created to simulate real experiments. Students can perform or observe experiments. In virtual labs, the results are consistently the same, time is saved and there is access to a variety of simulated chemicals and equipment (Rizman Herga, 2015). The advantage of working in VR is safety, given that there is no possibility of chemical accidents, and lower long-term costs, as experiments can be repeated as many times as desired without using actual chemicals (Lu, Xu and Zhu, 2021). However, Rizman Herga (2015) points out a significant disadvantage: the lack of manual skills training, which students cannot develop in virtual labs. This means that while virtual labs cannot replace actual lab work, they can contribute to students' knowledge (Rizman Herga, 2015). Lewis et al. (2014, cited in Havlíčková et al., 2018) criticise virtual labs for inaccurately representing real samples and their superficiality. Disadvantages also include experimental results that are not always accurate or are presented superficially (Lu, Xu and Zhu, 2021).

2 Methodology

Research aims and problem

The aim of the study was to investigate possible applications for learning chemistry with the VR glasses Meta Oculus Quest 2 and to test the usability of the selected application for teaching chemistry.

We set two research questions:

Q1: Which applications are suitable for teaching chemistry in virtual reality with Meta Oculus Quest 2?
Q2: How useful is the most appropriate application for teaching chemistry? What are the advantages and disadvantages of this application?

2.1 Methodology

Between March and May 2023, we reviewed five potential chemistry teaching applications for VR goggles, specifically Meta Oculus Quest 2. We searched the Meta website (https://www.meta.com/experiences/) for keywords such as chemistry, education and virtual lab. Each application was then evaluated based on the following criteria: cost, content, possibility of conducting virtual experiments, and the added value of VR technology for students. Thus, we obtained data for the first research question Q1.

After the review, we selected the most suitable application *The VR Chemistry Lab* and in May 2023 tested it with students from a high school as a case study. The participants wore a VR headset and operated hand controllers. The students initially familiarised themselves with the VR equipment and basic use of the VR glasses, which we had introduced to them. After entering the virtual lab, they first familiarised themselves with the layout, inventory, and safety equipment. They subsequently performed a virtual experiment, which took them about 15 minutes (Figure 2). After the virtual experiment, they completed a student learning sheet, which may be found in the appendix.

We obtained the data for Q2 through observation, the completed student learning sheet (following the virtual experiment) and a discussion among observers, the teacher and students after the virtual experiment and the students' learning sheet had been completed. The course of the research is outlined in the research plan (Figure 1).

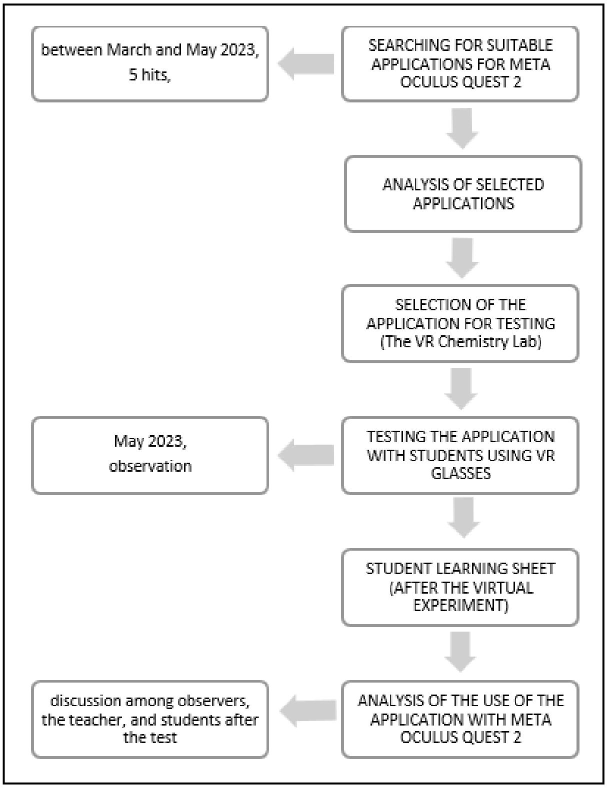


Figure 1: Research plan.
Source: own.

Figure 2: Conducting the virtual experiment with students.
Source: Mojca Oprčkal.

Sample

The participants (five female, one male) in our study were high school students (N = 6) in their first year of the gymnasium programme at the Third Grammar School in Maribor, Slovenia. Participants were students who were members of the chemistry club, which indicates they had greater skills and interest in chemistry. Their current grade point average in that school year was 4,0. We obtained the consent of the students to participate in the study.

We reviewed five applications with chemistry content available on the website www.meta.com. Together with the students, we tested one selected application, *The VR Chemistry Lab*, which is presented in the Results section.

Meta Oculus Quest 2 glasses

To conduct the virtual experiment, we used Meta Oculus Quest 2 VR glasses, as shown in Figure 2 above. To ensure a good fit and comfort, we also purchased the Oculus Quest 2 Elite strap. This ergonomic strap not only improves stability, but has a dial for tightening the ring, which contributes to extended use (Meta Quest 2, n.d.). Further, Oculus Quest 2 supports the use of VR glasses without a controller provided that the application supports this feature (Horvat, 2020). To use the goggles, one needs the Oculus Quest app on a smartphone, a Meta account to log into, and a good Internet connection. The wireless functionality of the VR glasses enables independent use for smaller and basic applications. Meta Quest glasses permit screen sharing in VR on a tablet, computer, phone or supported Chromecast device. We used this feature in our research to monitor the students during their virtual experiment and assist them when needed.

The VR Chemistry Lab application

The VR Chemistry Lab Simulation is a three-dimensional immersive representation of a conventional American school science laboratory (Hu-Au, et al., 2023). The virtual reality chemistry lab was created using Unity3D and replicates a physical lab classroom (Hu-Au and Okita, 2021). In the first practical session "Single Mixture Exercise", anhydrous copper(II) chloride had to be mixed with water and then a piece of aluminium foil had to be added to the aqueous solution. After the experiment, students can also investigate the sub-molecular level of the reaction. This lab activity is recommended for middle to high school chemistry students (ages 11–18) by the American Association of Chemistry Teachers (AACT, 2020, cited in Hu-Au and Okita, 2021). It follows the 'cookbook' style for lab design and provides detailed procedural steps to be followed exactly (National Research Council, 2006, cited in Hu-Au and Okita, 2021). More information about the application can be found in Hu-Au and Okita (2021) and Hu-Au, et al. (2023).

3 Results

3.1 Applications for virtual reality in chemistry (RQ1)

Table 1 below presents five applications with chemical content meeting the criteria (cost, content, possibility of conducting virtual experiments, added value of VR technology) suitable for the 1st year of high school, gymnasium programme.

Table 1: Applications for use with Meta Oculus Quest 2

Application	Cost/ username	Content	Possibility of conducting virtual experiments	Added value of VR
Nanome	free	different molecular representations	No	+
Abelana's Atom Maker	EUR 9.99	building structure of 3D molecules, simulating an entire protein made of hundreds of atoms	No	++
The Big Table	EUR 2.99	Bohr diagram, atomic orbitals, energy levels, electron configurations	No	+
Cyber Dose	EUR 7.99	periodic table, subatomic particles, elemental properties	No	+
The VR Chemistry Lab	EUR 2.99	a sample's molecular structure, manufacture and usage effects, properties of substances	Yes	++

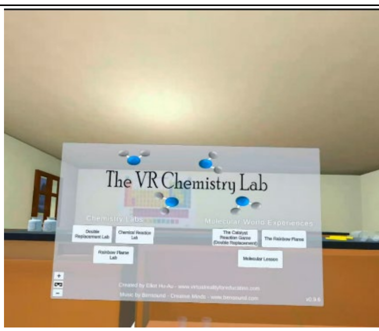
Legend:
+*game, motivation*
++ *meaningful added value, submicroscopic view*
+++ *in connection with learning objectives, didactically and content-wise correct*

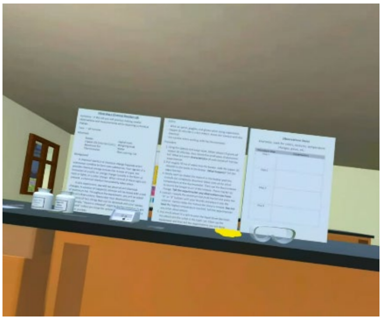
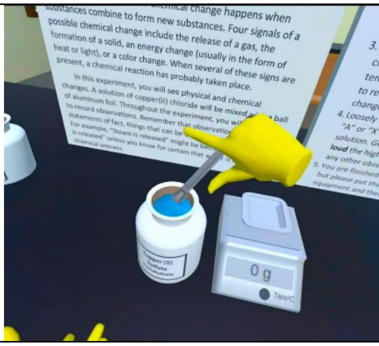
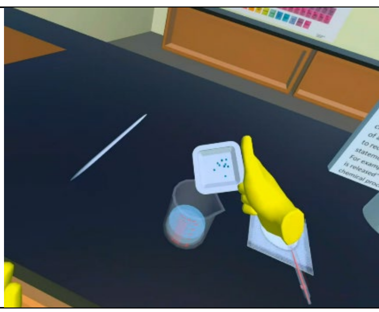
We found that of the five applications, only one (*Nanome*) is freely accessible and only one (*The VR Chemistry Lab*) offers the possibility to perform a virtual experiment. In terms of content, two applications are suitable for the first year of high school: *The VR Chemistry Lab* and *Abelana's Atom Maker*. *The Abelana's Atom Maker* application could be used in the section on Particles (building blocks) of matter where students learn about orbitals and the arrangement of electrons in energy levels or orbitals in atoms and ions of representative elements (Chemistry Curriculum, 2008). *The VR Chemistry Lab* application, on the other hand, could be used in the Chemical Reaction as Substance and Energy Change section where students learn about energy changes in chemical reactions and distinguish the properties of reactants and products (Chemistry Curriculum, 2008). As an added value, we identified motivation through gamification and a submicroscopic perspective in all applications. Despite a small number of experiments and identifying some shortcomings before implementation, we found *The VR Chemistry Lab application* to be the most suitable for testing with first-year high school students among all of the applications reviewed.

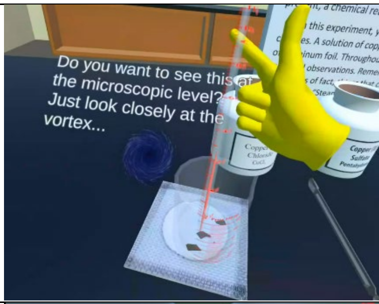
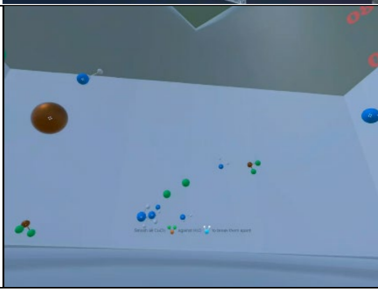
3.2 The application The VR Chemistry Lab (RQ1)

The VR Chemistry Lab application includes multiple experiments. We selected the Chemical Reaction Lab experiment, which introduces the basics of chemical reactions. In the experiment, a reaction occurs between copper(II) chloride, water and aluminium foil. The sequence of the experiment in the virtual laboratory of the selected application is presented below (Table 2).

Table 2: Course of the virtual experiment

	In the virtual environment, you first select which experiment you would like to perform. In our case, we choose Chemical reaction.

	We first read the instructions for conducting the experiment. Then, following the instructions, we put on a protective coat, gloves and safety glasses.
	We weigh out 0.5 g of copper(II) chloride.
	We pour 30 mL of water into the beaker.
	We add the weighed copper(II) chloride to the beaker of water and stir so that it dissolves. We measure the temperature.

	We add crumpled aluminium foil.
	We observe the course of the reaction and make another temperature measurement.

Source: Screenshots from the application The VR Chemistry Lab

Users can repeat the virtual experiment multiple times without consuming chemicals, as they would in a real lab. The application allows working with simulated chemicals that may be expensive or unavailable in a school lab. Since the experiment is conducted virtually, there is no risk of a hazardous situation with simulated chemicals during the experiment. Students can explore the submolecular level of chemicals. Mastering object manipulation in the virtual lab is crucial as objects can easily fall to the floor. Weighing and measuring becomes more challenging and requires precision with the controllers. Measurements of substances can be less accurate due to difficulties with reading scale numbers. The available inventory is limited. Some items such as waste containers for hazardous chemicals and glass stirring rods are missing. The application also has some technical inaccuracies, such as incorrect colours of chemicals and molecular representations. The application is also a paid service and the instructions are lengthy and written in English. It is not possible to write the results down on the worksheet displayed.

3.3 Results of the student learning sheet following the virtual experiment (RQ2)

After the virtual experiment, students were required to complete a learning sheet (see the appendix). The aim of evaluating the results was to assess the level of knowledge the students acquired through use of the virtual laboratory and VR glasses. The worksheet comprised six tasks related to the experiment conducted in the virtual laboratory. In the first task, students had to list the laboratory inventory used during the experiment. All six students correctly identified the laboratory inventory. For the second task, students had to list the chemicals they had used. Three students correctly stated that they had used copper(II) chloride and aluminium in the experiment, while the other three mentioned having used only copper(II) chloride. The third task required students to write a well-organised chemical reaction. No student wrote a completely accurate chemical reaction that occurred during the experiment. Students struggled with expressing the aggregate states, chemical formulas, and appropriate coefficients. In the fourth task, students had to write the reactants and products of the chemical reaction. Three students correctly identified the reactants and products of the reaction. During the experiment, students could determine whether the reaction was exothermic or endothermic by measuring the temperature. Therefore, we included the determination of the reaction type and an explanation of why the reaction is exothermic or endothermic in the fourth task. Four students correctly stated that the reaction was exothermic, because heat had been released during the reaction. The sixth task involved a computational example related to the experiment. Based on the data about the quantity of copper(II) chloride and aluminium, students had to calculate how much copper was produced in the reaction. No student solved the task correctly. In most cases, students either wrote down the data or left the task incomplete.

3.4 Results of the observations, discussions among observers, the teacher and students after the test (learning and experimentation skills) (RQ2)

The students mostly focused on the use of VR technology and less on the content aspect of the experiment. They encountered difficulties with the controllers, which led to challenges with weighing, pouring, measuring and rearranging the inventory. Despite having the opportunity to repeat the experiment several times, they were unable to do so due to time constraints. The students needed around 15 minutes to carry out the virtual experiment. Beforehand, they familiarised themselves with the VR equipment and its use, which is essential before the first VR experience. After the experiment, they completed a learning sheet, which is also an important part of the experience to ensure that students retain the basics.

Observations revealed that they paid too little attention to chemical safety given the virtual environment. They spent more time exploring the submicroscopic view of the 3D reaction, which is often inaccessible to them. Both the teacher and the students agreed that the main purpose of the application was to enrich and motivate the lessons.

However, despite the interesting experience, the students expressed that they would prefer real laboratory experiments. They pointed out disadvantages such as controller issues, discomfort, headaches and awkward movements. Perceived advantages included the potential motivation, the opportunity to experiment with hazardous chemicals, and the submicroscopic view. Students thought the VR glasses were more suitable for a game. The chemistry teacher expressed the belief that with the current underdeveloped applications virtual reality (VR) technology does not hold great potential to replace real laboratories. The costs are also too high for schools, unless funding is available. The teacher emphasised that educators need to familiarise themselves with the equipment and its use before incorporating VR technology into lessons. In terms of potential applications in chemistry, the teacher envisages its use for submicroscopic visualisations, reactions, and the formation of chemical and molecular bonds. It could also be used in certain laboratory experiments, especially for enrichment and motivation.

4 Discussion

We may conclude from the small number of applications with chemical content which we found (just 5) that this area is not yet sufficiently developed. We had expected more suitable applications, since virtual labs, albeit not designed for VR glasses, have been available for some time (Rizman Herga, 2015). The available applications are not suitable for use in the classroom since they are not aligned with the curriculum, as also discussed by Dinther et al. (2023). They are chiefly intended for play and motivation. It would be necessary to refine them conceptually and didactically. For useful and meaningful applications with chemical content for primary and secondary schools, it is crucial to involve experienced educationalists, chemists and computer scientists.

During the implementation itself, we encountered challenges with the technical equipment and Internet connection, which had to be strengthened before the application could function. Due to the initial exposure and problems with using the VR technology, students did not achieve as much substantive knowledge as indicated by their completed learning sheets. Ernawati and Ikhsan (2021) showed in their research that students who use a virtual laboratory can achieve higher cognitive achievements than students relying on conventional methods. In the research, no significant progress in knowledge can be expected as users were more focused on the technical execution, which is different from the real-life experience. Only one student, who already had experience with computer games, showed a better mastery of VR technology. In order to use VR effectively, students need more experience with handling the controllers so that they can focus on the content and acquire pedagogical and experimental skills. However, the teacher's in-depth knowledge of using VR technology is essential for teaching students how to use the VR glasses. Yıldırım et al. (2020) stresses the need for training in the use of this technology and suggests the steps mentioned in the Introduction section. Despite this, it is felt that students do not gain as many lab skills and as much knowledge as they would with real experiments. Rizman Herga (2015) also mentions a substantial disadvantage, emphasising the lack of manual skills training, which students cannot develop in a virtual lab. In this virtual lab, students learn basic lab techniques (weighing, measuring, mixing) but do not develop real manual skills. A limitation is the lack of multisensory learning because factors like odours, temperatures and the true colours of substances are not captured. Before implementation, it was known that the colour of the mixture was irregular, yet no student noticed this during the experiment, which is a significant problem in the real world. Due to the virtual environment, the students were not attentive enough in terms of safety, which led to a decrease in awareness and a sense of dealing with dangerous chemicals. In contrast, one advantage is the absence of potential hazards (VR), as also mentioned in the study by Ernawati and Ikhsan (2021). The use of VR glasses currently represents a considerable financial investment for schools, which is also mentioned by Muz and Yüce (2023) after reviewing 23 research studies. Namely, not all students were able to carry out the experiment at the same time. Both the students and the teacher agreed that the central purpose of the application was to enrich chemistry lessons. If the application is appropriate in terms of didactics and content, VR technology can be particularly useful while dealing with abstract submicroscopic content (Frevert and Fuccia, 2021). We believe the application used has the added benefit of providing students with a submicroscopic visualisation in 3D, which would give them a basis for understanding the reaction. Still, it is not yet clear from the tested application whether the added value of a VR lab in a VR environment can adequately replace students' real experimental work.

5 Conclusion

Due to the limitations of our research and time constraints, we did not include an introductory application for the use of VR glasses. It would be useful to test the virtual experiment with students already familiar with VR technology as they could then focus solely on the content, not the technology. If repeated, we would involve students with different academic achievements in chemistry to see how VR technology affects their learning and experimental achievements. For further research, a comparison could be made between the knowledge gained by performing experiments traditionally (live) and performing the experiment in a virtual lab. It would be worth investigating the extent to which the use of a high-quality virtual laboratory provides other insights, such as: improved submicroscopic visualisation, whether the effect of possible repetitions with different amounts of reactants and different conditions is suitable for conclusions and syntheses etc., or even whether a combination of real and virtual experiments can be used in didactically meaningful adaptations. We wish for the development of virtual laboratories to move in the direction of a didactically meaningful, educationally valuable and accessible application. Before VR technology can be used in chemistry lessons, applications must be developed and their appropriate use well considered. To avoid mistakes, the development of applications suitable for teaching should undergo similar reviews as textbooks.

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https://www.youtube.com/watch?v=9UHYTpfoxmM.đ

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Appendices:

A. Translation of the student learning sheet

Programme:
Class:
Final Grade in Chemistry:

VR LABORATORY: CHEMICAL REACTION
(The VR Chemistry Lab)

1. List the laboratory equipment you used during the experiment.

2. List the chemicals you used during the experiment.

3. Write down the balanced chemical reaction that occurred. Don't forget the states of matter.

4. List the reactants and products of the reaction that occurred.

REACTANTS:
PRODUCTS:

5. Is the reaction endothermic or exothermic? Explain.

6. Computational problem related to the experiment.

In the experiment, you used 0.5 g of copper(II) chloride and 3 g of aluminium, which reacted with each other. Aluminium chloride and copper were formed. Calculate how many grams of copper are produced in the reaction.