Virtual Reality for educational purposes

CircutexVR

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Abstract

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Abstract This document delves into the potential of virtual reality within the realm of learning, showcasing its application through the Textile Laboratory Simulator (CircutexVR). This simulator, developed for the CircuTex project, is designed to facilitate an online course on circular economy for fibrous composites and technical textiles. The aim is to assist students enrolled in relevant fields at their universities in enhancing their sustainability competencies. Additionally, the course aims to raise awareness about mitigating the impact of fibrous composites and technical textiles on climate change.		
Keywords Virtual reality, Textile Laboratory Simulator, Constructivist learning, Experiential, Interactive, Immersive, Feedback, Exploration, Knowledge construction, Interaction, Skills acquisition		

Contents

1 Introduction

Virtual Reality (VR) has rapidly transcended its traditional realm of entertainment, emerging as a dynamic force with immense potential in educational domains. This thesis seeks to explore the transformative impact of VR technology within the educational landscape, shedding light on its practical and transformative application through the development of the Textile Laboratory Simulator known as CircutexVR, an integral component of the Circutex project.

Simulators, such as CircutexVR, offer a unique advantage in educational settings due to their immersive nature. They provide learners with a realistic and interactive environment where they can engage in hands-on experiences without the constraints of physical resources or safety concerns. By simulating real-world scenarios, simulators enable learners to experiment, make mistakes, and learn from them in a risk-free environment. Additionally, these simulations incorporate feedback mechanisms that alert users whenever they attempt actions that could pose a risk in real-life scenarios. This feature ensures that learners maintain awareness of potential dangers, enhancing the overall safety and effectiveness of the learning experience.

Furthermore, simulators allow for the exploration of complex concepts and processes that may be difficult or costly to replicate in traditional educational settings. For instance, in the case of CircutexVR, learners can delve into the intricacies of textile manufacturing processes, explore the principles of circular economy within the context of fibrous composites and technical textiles, and interact with virtual machinery and materials.

The evolution of VR technology has witnessed remarkable strides, rendering it more accessible and adaptable than ever before. This evolution has sparked a deep interest in leveraging VR's immersive capabilities to revolutionize conventional educational approaches. This research primarily focuses on investigating the viability and effectiveness of VR technology as a potent learning tool, with an emphasis on the application developed—CircutexVR. This innovative VR tool serves as a complementary asset within an online course focused on circular economy principles for fibrous composites and technical textiles.

2 Virtual Reality

2.1 Definition and Concepts

Virtual Reality (VR) tech is changing fast, making it tricky to nail down a definition based on specific gadgets that might become old news sooner than we think. The real deal here is focusing on some core principles that go beyond trendy tech, so we are not left in the dust. One big challenge is putting together a definition that captures what VR is all about while keeping it flexible enough for how we see it now and whatever comes next (LaValle, 2023).

Cutting to the chase, the heart of the matter with VR is getting living things to act a certain way by messing with their senses, all while keeping them blissfully ignorant of any outside meddling. This definition highlights how VR sucks people into its world, where they are doing things and reacting to stuff without really clocking that it's all make-believe (LaValle, 2023).

Now, breaking it down even more, the definition of VR comes down to four key bits:

- Targeted Behaviour: People dive into experiences cooked up by VR whizzes, like exploring new places, hanging out in fake worlds, or catching a flick (LaValle, 2023).
- Inclusive of Various Life Forms: VR is not just for us humans (Figure 1); it's for all kinds of living things, from people to bugs, fish, rodents, or even primates. It's a handy tool for poking around in the lives of different critters (LaValle, 2023).
- Artificial Sensory Stimulation: VR gets things going by tinkering with how living things sense stuff. It uses tech smarts to tweak or crank up the senses, giving a taste of what it's like to be knee-deep in the experience (LaValle, 2023).
- Awareness Shift: VR messes with the minds of whoever is in the hot seat. Even though it's all fake, the person or critter in there does not catch on to anything outside the bubble, making it feel super real and natural (LaValle, 2023).

2.2 Historical Perspective of Virtual Reality

The story of virtual reality (VR) is kind of complicated and has been changing over time, starting back in the 1960s and 1970s (Mazuryk, 1999). At first, people used early VR mostly for shows and performances, trying to make it feel like you are in ancient or nature scenes (Dixon, 2006). The history also includes making VR devices better to give users a cooler experience (Santana, 2018). They are also looking into using VR for technical and professional communication, especially for teaching new things in different ways (Tham, 2018).

Here is a list of the first VR devices:

- 1838: The stereoscope (Charles Wheatstone, Figure 1)

Figure 1. The stereoscope with Charles Wheatstone (KCL, 2016)

- 1939: The View-Master (William Gruber)
- 1849: The lenticular stereoscope (David Brewster)
- 1929: Link Trainer the First Flight Simulator (Edward Link, Figure 2)

Figure 2. Link Trainer Flight Simulator on Exhibit © NAS Fort Lauderdale Museum (Nasflmuseum, 2014)

- 1950: Sensorama (Morton Heilig)
- 1960: The first VR Head Mounted Display (Morton Heilig)
- 1961: Headsight, the first Motion Tracking Head Mounted Display (Comeau and Bryan from Philco Corporation)
- 1965: The Ultimate Display (Ivan Sutherland, Figure 3)

Figure 3. The Ultimate Display by Ivan Sutherland (Kent Bye, 2016)

- 1966: Flight Sim (Furness)

- 1968: Sword of Damocles (Ivan Sutherland)
- 1969: Artificial Reality (Myron Kruegere)
- 1972: Digital Flight Sim (General Electric)
- 1975: VIDEOPLACE (Krueger)

These are just some of the devices that had something to do with Virtual Reality in the beginning of this concept, but it was not known as ‘Virtual Reality’ until 1987 when Jaron Lanier, founder of the visual programming lab VPL, presented the term as we know it nowadays. Through his company research, Jaron developed virtual reality gear (Dataglove, EyePhone, Figure 4) and with this they were the first company to sell virtual reality goggles. (VRS, 2020).

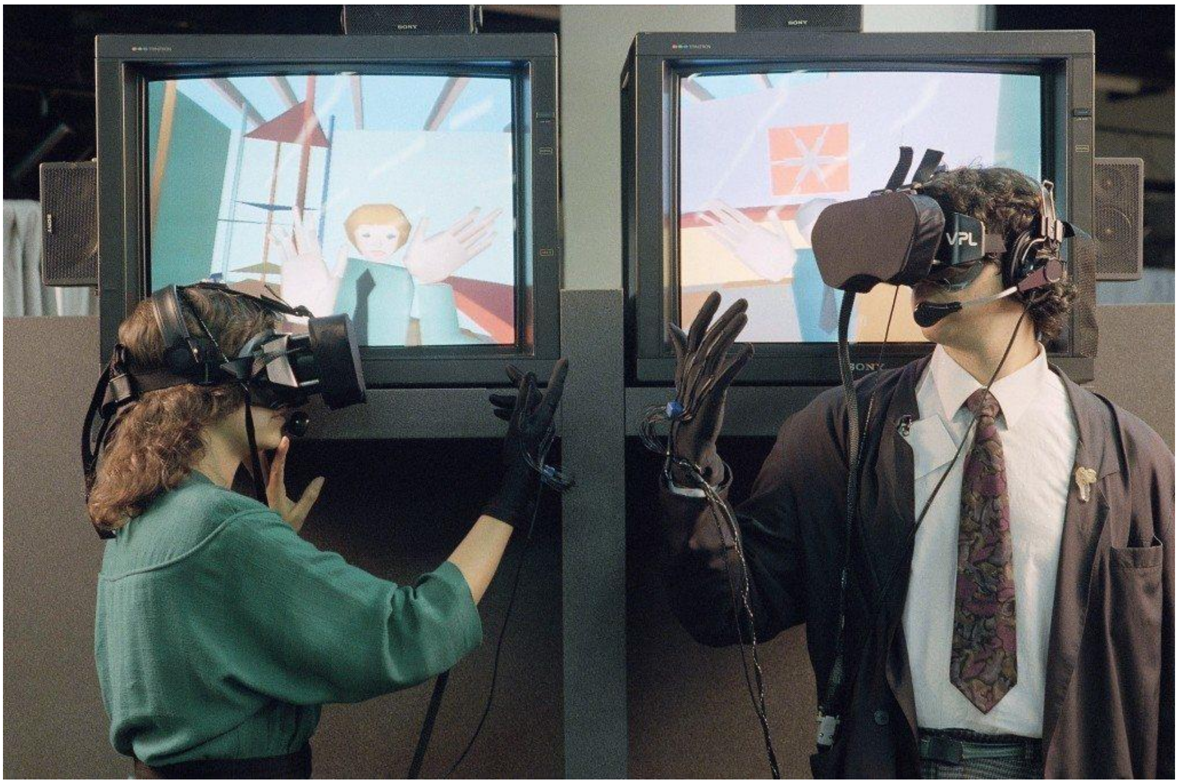


Figure 4. Eyephone by Jaron Lanier (Paul Sorene, 2014)

From then on, the devices began to be designed not only for entertainment, like video games, but also for training with simulators. One notable milestone occurred in 1989 when NASA developed a simulator for training astronauts, which included special gloves for touch interaction (VRS, 2020). This marked an early recognition of VR's potential for immersive training experiences in high-stakes environments.

As technology advanced, VR continued to evolve, with significant developments in the consumer market. In 2016, the landscape of virtual reality took a giant leap forward with the release of the Oculus Rift by Oculus VR (Meta, 2021) and the HTC Vive by HTC

(Gamespot, 2018). These VR headsets brought immersive experiences into the homes of consumers, revolutionizing how people interacted with digital content. The Oculus Rift garnered widespread attention for its high-quality display and intuitive motion-tracking capabilities, while the HTC Vive (Figure 5) distinguished itself with its room-scale tracking system, allowing users to physically move within the virtual environment.

The release of these popular VR headsets in 2016 marked a turning point in the accessibility and adoption of virtual reality technology. With increasingly powerful hardware and a growing library of immersive experiences, VR became not just a niche technology, but a mainstream phenomenon with applications spanning entertainment, education, healthcare, and more.

Figure 5. HTC Vive (Nick Pino, 2022)

2.3 Immersive Experiences and Engagement

Research on immersive experiences and engagement in VR has shed light on the potential applications of this technology in various fields. Stone (2013) emphasizes the educational benefits of immersive virtual worlds, particularly in online learning. Engaging in virtual reality research involves actively taking part, observing, and fully immersing oneself in the scenari-os. This is essential to thoroughly understand the possible educational benefits and drawbacks of the environment. Flavián (2019) underscores the role of technological embodiment in creating effective virtual experiences for potential tourist destinations. Škola (2020) fur-ther supports the positive impact of virtual reality, especially in cultural heritage, by demon-strating high levels of presence, immersion, and engagement in an archaeological VR ap-plication. Grinberg (2014) contributes by recognizing social interaction as a pivotal element of user involvement in virtual realms, indicating that the communal aspects of these settings are essential for encouraging a strong feeling of involvement.

2.4 Challenges for not experienced Virtual Reality users

A review of challenges in virtual reality (VR) systems by Chong (2018) highlights the need for a better understanding of user experience issues to improve acceptance of the technology. Pausch (1994) emphasizes the difficulties in VR development, including limited hardware and uncertain interface paradigms. Technical issues in VR experiments, such as the impact of mounting headsets on participants, are discussed by Szczurowski (2022). Moldoveanu (2015) focuses on the challenges of applying VR in medical rehabilitation, including cost-related issues, human-computer interface problems, and the need for alignment of patient expectations. These studies collectively underscore the need for improved user experience, technical development, and cost-effective solutions in VR systems.

Investigate on hand tracking (Figure 6) in virtual reality has appeared that it can altogether impact client involvement. Voigt-Antons (2020) found that hand tracking can lead to higher immersion and nearness, but lower excitement and dominance, compared to controller intuitive. Be that as it may, members still favoured the interaction sort with visualized hands and controllers. Additionally, Hameed (2021) detailed that hand tracking driven to lower play terms and trigger frequencies, but higher seen mental workload. These discoveries propose that whereas hand tracking can upgrade the immersive encounter, it may moreover require more cognitive exertion. Castro (2021) and Dorfmüller-Ulhaas (2001) both created frameworks for hand tracking in VR, with the previous focusing on a low-cost framework for VR situations and the last mentioned on a finger following framework for expanded reality. These thinks about collectively highlight the potential of hand following in VR, but also the need for encourage inquire about to optimize its convenience and client encounter.

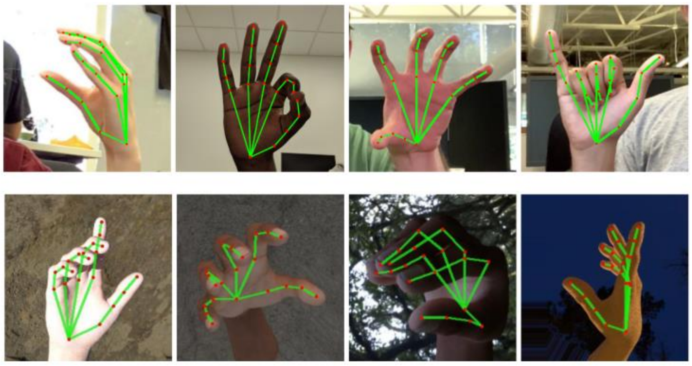


Figure 6. Hand tracking. (Devin Coldewey, 2019)

3 Virtual Reality in Education

3.1 Constructivist Learning

Constructivist learning theory (Figure 7) posits that learners actively construct their own understanding and knowledge through experiencing and reflecting on the world around them. This stands in contrast to traditional instructivist approaches, where knowledge is transmitted from teacher to student in a more passive manner. By engaging learners in meaningful activities and experiences, constructivist learning promotes deeper understanding, critical thinking, and problem-solving skills.

Peach-Squibb (2014) discusses how constructivist principles can be applied in educational settings to create environments that encourage exploration, experimentation, and collaboration. By allowing learners to interact with materials and concepts in a hands-on manner, educators can facilitate the construction of knowledge that is meaningful and enduring. Miikkulainen (2003) extends this idea by presenting a computational model of constructivist learning that simulates how neural networks adapt and evolve based on environmental stimuli. This model provides insights into the underlying mechanisms of learning and offers practical applications in fields such as artificial intelligence and robotics.

Figure 7. Constructivist learning scheme. (Instructional Coaches)

In the realm of machine learning, Li (2017) proposes a constructivist approach that prioritizes transparency and interpretability in model development. By involving learners in the process of constructing and refining machine learning algorithms, Li argues that the resulting models are not only more accurate but also more understandable and trustworthy. Similarly, Nurhasnawati (2011) explores how constructivist principles can enhance science education by encouraging students to actively engage in inquiry-based learning activities. Through hands-on experiments, collaborative projects, and reflective discussions, students develop a deeper appreciation for the scientific method and gain a more comprehensive understanding of scientific concepts.

The integration of virtual reality (VR) technology into constructivist learning environments offers exciting opportunities to enhance engagement, immersion, and interactivity (Figure 8). Collins (2018) and Meri-Yilan (2019) discuss how VR simulations and experiences can transport learners to virtual worlds where they can explore, manipulate, and interact with complex concepts in a safe and controlled environment. By providing opportunities for hands-on experimentation and exploration, VR enables learners to construct their own understanding of abstract or difficult-to-grasp concepts, leading to deeper learning outcomes.

Figure 8. Students learning chemistry with VR. (Sophie Thompson, 2023)

Moreover, Sung (2002) and Nitu (2018) highlight the potential of VR in specialized domains such as computer graphics and architecture. Through immersive VR environments, students can visualize and interact with complex three-dimensional models, gaining insights that would be difficult to achieve through traditional 2D representations. Whether exploring the intricacies of architectural design or delving into the principles of computer graphics rendering, VR empowers learners to actively engage with content in ways that stimulate curiosity, creativity, and critical thinking.

3.2 The Role of Virtual Reality in Education

Virtual reality (VR) has been increasingly recognized as a valuable tool in education, offering a range of benefits (Sala, 2016). It has been found to be particularly effective in engaging students (Figure 9), catering to different learning styles, and providing a safe environment for experiential learning (Serin, 2020). The multi-sensory nature of VR enhances the learning experience, making it more effective than traditional methods (Christou, 2010).

Figure 9. Illustration of a person learning about the solar system with VR. (Sophie Thompson, 2023)

Despite the initial cost challenges, the educational benefits of VR are compelling, especially in fields like engineering where it can provide immersive and interactive learning experiences (Abulrub, 2011). VR offers students the opportunity to explore complex concepts in a hands-on manner, leading to deeper understanding and retention (Sala, 2016). This experiential learning approach can bridge the gap between theory and practice, preparing students for real-world challenges (Serin, 2020).

Moreover, VR can simulate scenarios that would be too dangerous, expensive, or impractical to replicate in a traditional classroom setting (Christou, 2010). For example, students studying medicine can practice surgical procedures in a virtual operating room without any risk to patients (Abulrub, 2011). This not only enhances their technical skills but also fosters critical thinking and decision-making abilities.

In addition, VR can facilitate collaborative learning experiences (Figure 10), allowing students to interact with each other and with virtual objects in real-time (Sala, 2016). This collaborative aspect mirrors the teamwork often required in professional settings, preparing students for future careers (Serin, 2020). By working together in virtual environments, students can learn from each other's perspectives and skills, enhancing their overall learning outcomes (Christou, 2010).

Figure 10. Two people working in real time with VR in a virtual environment. (Sophie Thompson, 2023)

The integration of VR into education offers numerous benefits, from increased engagement and retention to the simulation of real-world scenarios (Abulrub, 2011). While there are initial cost challenges, the long-term educational advantages justify the investment (Sala, 2016). As technology continues to advance, VR has the potential to revolutionize the way students learn, providing them with immersive and interactive experiences that enhance their understanding and prepare them for future success (Serin, 2020).

3.3 Early Developments and Pioneers

Ivan Sutherland's pioneering work in virtual reality (Figure 11) has laid the foundation for its potential in education (Sutherland, 1968). Dede (2010) and Christou (2010) both highlight the multi-sensory and interactive nature of VR, which can enhance learning experiences. Fällman (1999) further emphasizes the role of VR in supporting complex understanding and mental models, particularly in non-intuitive subjects.

Moreover, Byrne (1994) underscores the potential of VR in presenting complex data, particularly in science education, by providing a 3-dimensional, immersive experience that can reduce the abstraction of concepts. These studies collectively underscore the potential of VR, inspired by Sutherland's work, in transforming education by providing more engaging, interactive, and effective learning experiences.

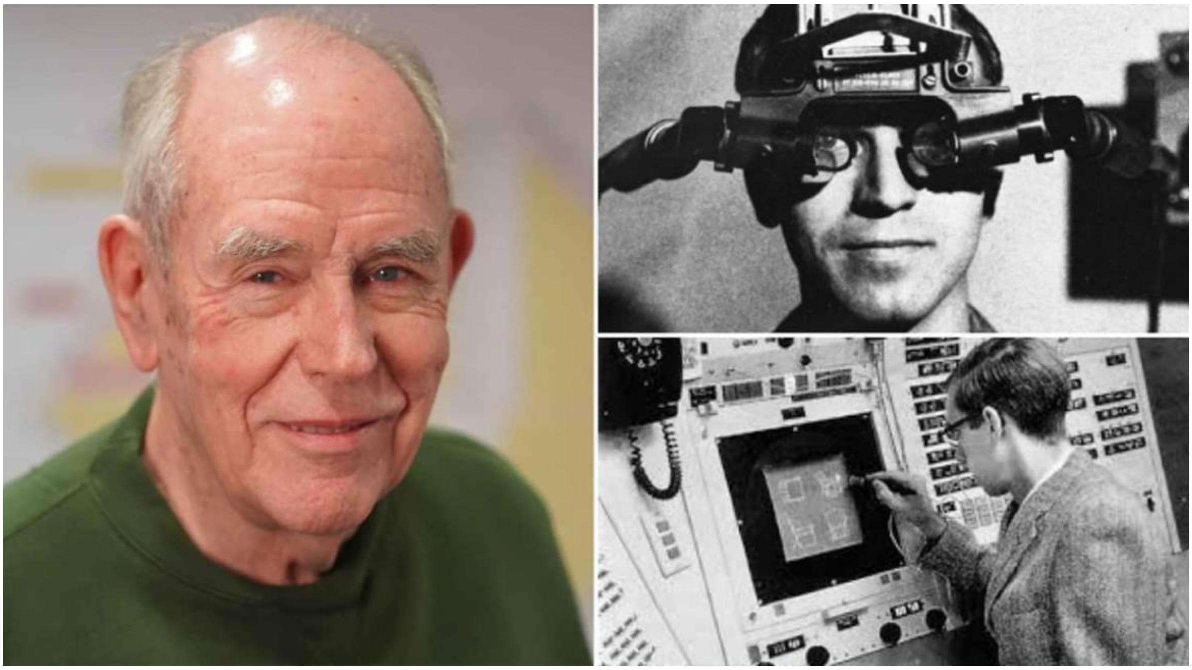


Figure 11. Ivan Sutherland. (Hannah Ward, 2023)

Furness III's work in VR military training and medical simulation has significantly advanced the field (Figure 12). Siu (2016) and Kizakevich (2006) both highlight the potential of adaptive VR training systems in improving medical skills acquisition and retention, particularly in minimally invasive surgery and multicausality triage.

Furness III's contributions to virtual reality technology have also had a profound impact on education. Satava (1997) further underscores the importance of integrating different VE modalities for medical training, a concept that Furness III has likely contributed to. Lastly, Stone (2006) discusses the potential of serious gaming in military clinical scenarios, an area where Furness III's work in VR simulation could have significant impact.

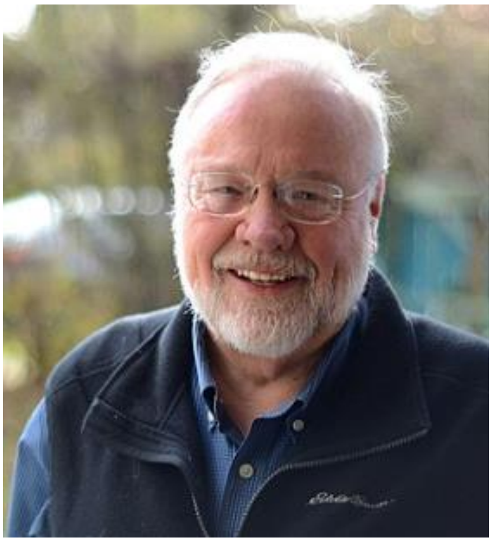


Figure 12. Thomas A. Furness III. (Wikipedia, 2023)

Laurel's work in the development of virtual reality for educational purposes has significantly influenced the field, as evidenced by a number of subsequent studies (Figure 13). Kuna (2023) and Alawadhi (2017) both highlight the potential of virtual reality in vocational education and training, with Kuna specifically discussing the use of virtual excursions.

Laurel's contributions to the field emphasize the importance of immersive and interactive learning environments that cater to diverse learning styles. Żmigrodzka (2017) further explores the impact of virtual reality on education, emphasizing the need to cater to diverse learning styles. O'Connor (2017) provides practical guidance for creating effective virtual reality learning environments, drawing upon Laurel's principles of narrative-driven experiences and learner empowerment.

These studies collectively underscore the transformative potential of Laurel's work in this area, demonstrating how her insights into the design of immersive and interactive educational experiences have shaped the development and application of virtual reality technology in education. Laurel's emphasis on storytelling and narrative-driven interactions has paved the way for innovative approaches to learning that leverage the unique capabilities of virtual reality technology to enhance engagement, promote deeper learning, and cater to diverse learner needs.

Figure 13. Brenda Laurel. (Wikipedia, 2024)

Chris Dede has been a pioneer in the development of virtual reality for educational purposes. His work has been instrumental in modernizing education through the use of virtual reality, as proposed by Malagaudanavar (2015). Dede's efforts have also contributed to the establishment of a national research and education program in virtual reality, as discussed by Zyda (1997).

Dede's contributions to the field of virtual reality in education are extensive and far-reaching. Through his research and advocacy, Dede has helped to highlight the potential of virtual reality as a powerful tool for transforming teaching and learning practices. One key aspect of Dede's work is his exploration of the multi-sensory and interactive nature of virtual reality, which enhances learning experiences by providing students with immersive and engaging environments. By leveraging the capabilities of virtual reality technology, Dede has shown how educators can create dynamic and interactive learning environments that cater to diverse learner needs and preferences (Harvard, 2018).

Furthermore, Dede's efforts have played a significant role in shaping the broader educational landscape. His advocacy for the integration of virtual reality into educational curricula has led to the establishment of national research and education programs focused on advancing the use of virtual reality in teaching and learning (Zyda, 1997). These programs provide educators with the resources and support they need to explore innovative approaches to education and harness the potential of virtual reality technology.

In addition to his research and advocacy efforts, Dede (Figure 14) has also been actively involved in the development of practical tools and resources for educators. Through initiatives such as the National Science Foundation's Virtual Reality Education Pathfinder program, Dede has worked to develop and disseminate virtual reality applications and resources for use in educational settings (Zyda, 1997). These initiatives provide educators with access to cutting-edge virtual reality technology and support their efforts to integrate it into their teaching practices.

Overall, Chris Dede's pioneering work in the development of virtual reality for educational purposes has had a profound impact on the field of education. His research, advocacy, and practical contributions have helped to advance our understanding of how virtual reality can be used to enhance teaching and learning practices, and his efforts continue to shape the future of education in the digital age.

Figure 14. Christopher Dede. (Harvard, 2018)

3.4 Evolution of VR in Educational Matters

The inception of virtual reality (VR) technology can be traced back to the 1960s, with Ivan Sutherland's development of the first head-mounted display system (Eve, 2018). Sutherland's creation, known as the "Sword of Damocles," laid the foundation for future advancements in VR technology and sparked interest in its potential applications. However, during this period, VR technology was primarily explored for military (Figure 15) and industrial purposes, such as simulation, training, and design (Krogh, 1998). Researchers and engineers focused on creating immersive environments that could replicate real-world scenarios, allowing users to interact with and manipulate virtual objects in three-dimensional space.

Figure 15. Virtual Reality for military training. (Greg Nichols, 2018)

Despite its early focus on military and industrial applications, VR technology continued to evolve throughout the late 20th century. In the late 1980s, significant strides were made in hardware development, with the introduction of goggles, datagloves, and datasuits (Ross, 2021). These advancements made VR technology more accessible and user-friendly, paving the way for its expansion into new domains.

As VR hardware became more sophisticated and affordable, researchers began to explore its potential applications in fields such as medicine, architecture, and entertainment (Giddings, 1996). In medicine, for example, VR simulations were used to train medical professionals and simulate surgical procedures, providing a safe and controlled environment for practice and learning (Ross, 2021). Similarly, in architecture, VR technology enabled architects to visualize and manipulate virtual building designs, allowing for more accurate and efficient planning and design processes (Giddings, 1996).

This diversification of VR technology opened new possibilities for innovation and creativity, leading to the development of immersive experiences and interactive simulations across various industries. In entertainment, VR technology revolutionized the gaming industry, allowing players to immerse themselves in virtual worlds and interact with digital environments in unprecedented ways (Ross, 2021). VR also found applications in film and television, with filmmakers exploring the potential of VR storytelling and immersive filmmaking techniques (Giddings, 1996).

Furthermore, VR technology was used in training and simulation applications across a wide range of industries, including aviation, manufacturing, and emergency response (Ross, 2021). VR simulations allowed trainees to practice and refine their skills in realistic and immersive environments (Figure 16), improving learning outcomes and performance (Giddings, 1996). This integration of VR into various industries highlighted the versatility and potential of VR technology to transform how we work, learn, and interact with digital information.

Figure 16. Surgery training with Virtual Reality. (Guy Campos, 2018)

Educators and researchers recognized the immersive and interactive nature of VR to create engaging and impactful learning environments. Virtual reality simulations allowed students to explore complex concepts in a hands-on manner, providing them with opportunities to visualize abstract ideas and engage in experiential learning (Krogh, 1998). Moreover, VR technology offered educators a new toolkit for designing dynamic and interactive lessons that catered to diverse learning styles and preferences (Eve, 2018). By incorporating VR into curricula, educators could supplement traditional teaching methods with immersive experiences that fostered critical thinking, problem-solving, and collaboration.

Today, virtual reality technology continues to play an increasingly important role in education, with educators integrating VR into curricula across various disciplines (Ross, 2021). VR offers students opportunities to explore concepts in depth, conduct virtual experiments, and engage in collaborative learning experiences (Figure 17). As VR hardware becomes more accessible and affordable, its potential to revolutionize education and transform the way students learn continues to grow (Krogh, 1998). However, challenges remain, including the need for more research into the effectiveness of VR in education, as well as the development of standards and guidelines for creating high-quality VR experiences (Giddings, 1996). Nonetheless, the future of VR in education looks promising, with ongoing advancements in technology and pedagogy driving innovation and expanding possibilities for teaching and learning.

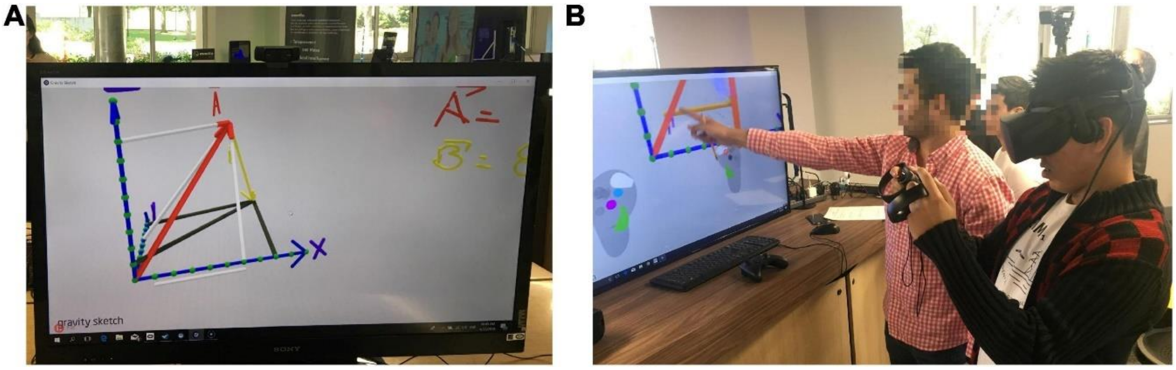


Figure 17. Learning vectors with virtual reality in "Gravity Sketch". (Esmeralda Campos, 2022)

3.5 Milestones and Key Advances

Over the past two decades, virtual reality (VR) has made significant strides, particularly in product design and manufacturing, where it is now a mature and usable tool (Berg, 2016). Its potential in education, medicine, and engineering has also been recognized, with VR being used to improve learning experiences, simulate visual tasks for robotic systems, and revolutionize the way we interact with digital information (Akinola, 2020; Chessa, 2010; Yin, 2021).

In education, VR has emerged as a powerful tool for enhancing learning experiences and engaging students in immersive virtual environments (Chessa, 2010). Educators have leveraged VR technology to create interactive simulations, virtual field trips, and hands-on learning experiences that complement traditional teaching methods (Akinola, 2020). By allowing students to explore complex concepts in a three-dimensional space, VR facilitates deeper understanding and retention of information, making learning more interactive and engaging (Yin, 2021).

In medicine, VR has been used to simulate surgical procedures, train medical professionals, and enhance patient care (Yin, 2021). VR simulations allow medical students and practitioners to practice surgical techniques in a safe and controlled environment, without risk to patients (Chessa, 2010). Additionally, VR technology enables the visualization of complex medical data, such as MRI scans and anatomical structures, in a three-dimensional space, enhancing diagnostic capabilities and treatment planning (Akinola, 2020).

In engineering, VR has revolutionized the design and development process, allowing engineers to visualize and manipulate virtual prototypes in real-time (Yin, 2021). VR simulations enable engineers to test and refine designs, identify potential issues, and optimize performance before physical prototypes are created (Chessa, 2010). This iterative design process not only accelerates product development but also reduces costs and improves product quality (Akinola, 2020).

These advancements have been driven by improvements in hardware and display technologies, which have made VR more accessible and comfortable for users (Yin, 2021). The development of high-resolution displays, motion tracking systems, and haptic feedback devices has enhanced the realism and immersion of VR experiences, making them more engaging and effective for education, medicine, and engineering applications (Chessa, 2010). As VR technology continues to evolve, its potential to transform various industries and improve the way we work, learn, and interact with digital information will only continue to grow (Akinola, 2020).

The hardware of virtual reality (VR) has seen significant advancements in recent years, with the introduction of new displays and input devices (Anthes, 2016). These developments have been driven by enthusiasts and have led to the creation of more affordable and robust technologies, such as haptic devices, controllers, and tracking technologies.

Despite these advancements, challenges remain, including motion-to-photon latency and barrel distortion (Mandal, 2013). Motion-to-photon latency refers to the delay between a user's movement and the corresponding visual feedback in the VR environment, which can cause discomfort and reduce immersion (Boas, 2012). Barrel distortion, on the other hand, occurs when the edges of the VR display appear distorted due to the curvature of the lenses, affecting the overall visual experience (Yin, 2021).

The potential for VR to create immersive experiences is evident, with the development of head displays and movement recognition (Boas, 2012). Head displays, such as head-mounted displays (HMDs), provide users with a high-resolution, stereoscopic view of the virtual environment, enhancing immersion and presence (Anthes, 2016). Movement recognition technologies, such as motion tracking and gesture recognition, allow users to interact with virtual objects and navigate virtual spaces using natural body movements (Mandal, 2013).

Further progress is expected in the field of virtual reality hardware, particularly in the areas of optical elements, display technologies, and digital processing (Yin, 2021). Advances in optical elements, such as improved lenses and light field displays, will enhance the clarity and realism of VR visuals, reducing eye strain and improving the overall user experience (Boas, 2012). Similarly, advancements in display technologies, such as higher refresh rates and wider field-of-view displays, will further enhance immersion and presence in virtual environments (Anthes, 2016).

Additionally, ongoing developments in digital processing, including advancements in graphics rendering and real-time tracking algorithms, will enable more realistic and interactive VR experiences (Mandal, 2013). These advancements will drive the continued growth and adoption of VR technology across various industries, including gaming, entertainment, education, and healthcare (Yin, 2021). As VR hardware continues to evolve and improve, the possibilities for creating immersive and engaging virtual experiences will only continue to expand.

3.6 Challenges and Benefits of Virtual Reality in Education

Virtual reality (VR) in education offers numerous benefits (Figure 18), including increased student motivation and engagement, and the ability to visualize complex concepts (Kavanagh, 2017; Youngblut, 1998). By immersing students in virtual environments, VR allows them to experience learning in a more interactive and hands-on manner, leading to higher levels of engagement and retention (Kavanagh, 2017). Additionally, the ability to visualize abstract or complex concepts in three-dimensional space can make learning more accessible and comprehensible for students, particularly those with diverse learning styles (Youngblut, 1998).

However, the widespread adoption of VR in education is hindered by technological limitations, cost, and logistical challenges (Kavanagh, 2017). The high cost of VR hardware and software, as well as the need for specialized equipment and technical expertise, can pose significant barriers to implementation for many educational institutions (Kavanagh, 2017). Additionally, logistical challenges such as limited access to VR resources and infrastructure can further impede the integration of VR into curricula (Kavanagh, 2017).

Despite these challenges, VR has the potential to significantly enhance the learning experience, particularly in areas such as general, engineering, and health-related education (Kamińska, 2019). In engineering education, for example, VR simulations can provide students with hands-on experience in designing and testing prototypes, allowing them to gain practical skills in a virtual environment (Kamińska, 2019). Similarly, in health-related education, VR can be used to simulate medical procedures and patient interactions, providing students with valuable clinical experience in a safe and controlled setting (Kamińska, 2019).

Three-dimensional virtual worlds, a subset of VR, provide unique educational experiences and opportunities for interaction (Eschenbrenner, 2008). In virtual worlds, students can explore virtual environments, interact with virtual objects and characters, and collaborate with peers in real-time, fostering social learning and collaboration (Eschenbrenner, 2008). These immersive and interactive experiences can enhance student engagement and deepen understanding of course material (Eschenbrenner, 2008).

Overall, while VR presents challenges, its potential to improve education is widely recognized (Youngblut, 1998). By providing students with immersive and interactive learning experiences, VR can transform education and prepare students for success in an increasingly digital and interconnected world. With continued advancements in technology and increased access to VR resources, the integration of VR into education is likely to become more widespread in the coming years (Kavanagh, 2017).

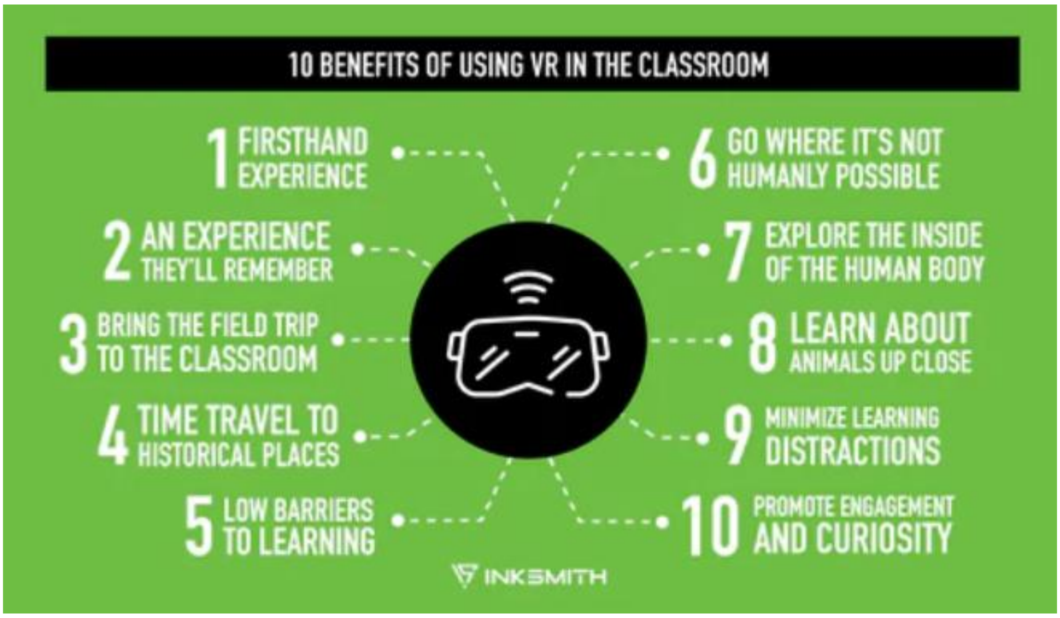


Figure 18. 10 Benefits of using VR in the classroom (Inksmith, 2019)

4 Case: CircutexVR

4.1 Introduction

CircutexVR is an application in virtual reality (VR) developed specifically for Meta Quest devices, including Meta Quest 2, Meta Quest 3, and Meta Quest Pro. CircutexVR was designed as a supplementary resource for an online course on the circular economy of fibrous composites and technical textiles; it is designed to smash up the future of sustainability education by giving students interactive environments.

This course, together with the universities of Romania, Greece, Lithuania, and Spain, aimed to uplift students' awareness in relevant areas of fibrous composites and technical textiles against climate change. CircutexVR allows students to benefit from their studies using a majorly virtual reality textile laboratory simulator in the development of a better understanding of all major concepts and principles applied.

CircutexVR includes eleven different experiments that emulate the ones taught in a class, thus offering students an exposure to practical experience through a virtual environment. From the fiber identification test and the abrasion tests on a Martindale machine to the determination of breaking strength of fibers using a dynamometer, tests cover everything that could have been studied in a theoretical manner by the learners.

Using the immersive capabilities of virtual reality, CircutexVR will take students through a process of a real-time experiment conducted by allowing the student to control equipment, followed by the prescribed experiment, and then analyzing results for coursework. Such an immersive learning experience would engage students but also help in building much deeper understanding and retention of the course material.

4.2 Tools and Technologies Used

The development and design of CircutexVR present cutting-edge tools and technology needed in the development of educational, immersive virtual experiences. This chapter tries to highlight the most critical roles played by Unity 3D, C#, Blender, and Meta Quest 2 towards developing CircutexVR.

Unity 3D provides the ideal ground for building CircutexVR, given that it is an intense, flexible, and top-quality virtual reality development platform. The tools that will be added through Unity make it possible to add details of the environment, physics fine-tuning, and be highly interactive in simulating the Textile Lab. It is compatible with Meta Quest 2 and can shorten the process, even installing and testing directly on the VR device.

Further boost to the developmental phase was through the Unity Asset Store and its huge community resources of ready models, scripts, and tools that could be used to make CircutexVR have more educational value.

C#

The programming language within the Unity platform is inbuilt, hence the choice of C#. This really eases scripting to cover the whole complexity of all the interactions, behaviors, and simulation dynamics taking place in the virtual laboratory.

C# being object-oriented, of course, it lets the code be developed upon a modular and scalable architecture that enables CircutexVR to iteratively refine and augment its features. In C#, it means executing interactive tutorials, real-time feedback mechanisms, and a comprehensive user interface, the critical essentials to the immersive learning experience that CircutexVR aims to avail.

Blender

Blender is an open-source 3D modeling and animation software, and hence one of the major tools in the creation of custom assets for CircutexVR. It entailed detailed modelling for laboratory equipment (Figure 19), such as textiles and environmental elements existing in the laboratories, coming up with a realistic and interactive environment. The Blender models are easily merged with Unity 3D. This offers great ease in the work of producing and processing this kind of asset, where there would be the possibility of a unified workflow for the graphical design and development teams.

The models created are designed to be low poly to accommodate the technical limitations of the Meta Quest 2, which supports only a limited number of polygons in its visual field. This approach ensures that the virtual environment operates smoothly without compromising the immersive experience by overloading the system. Although these models are not as detailed as their real-life counterparts, they are sufficiently representative to provide a realistic and interactive learning environment.

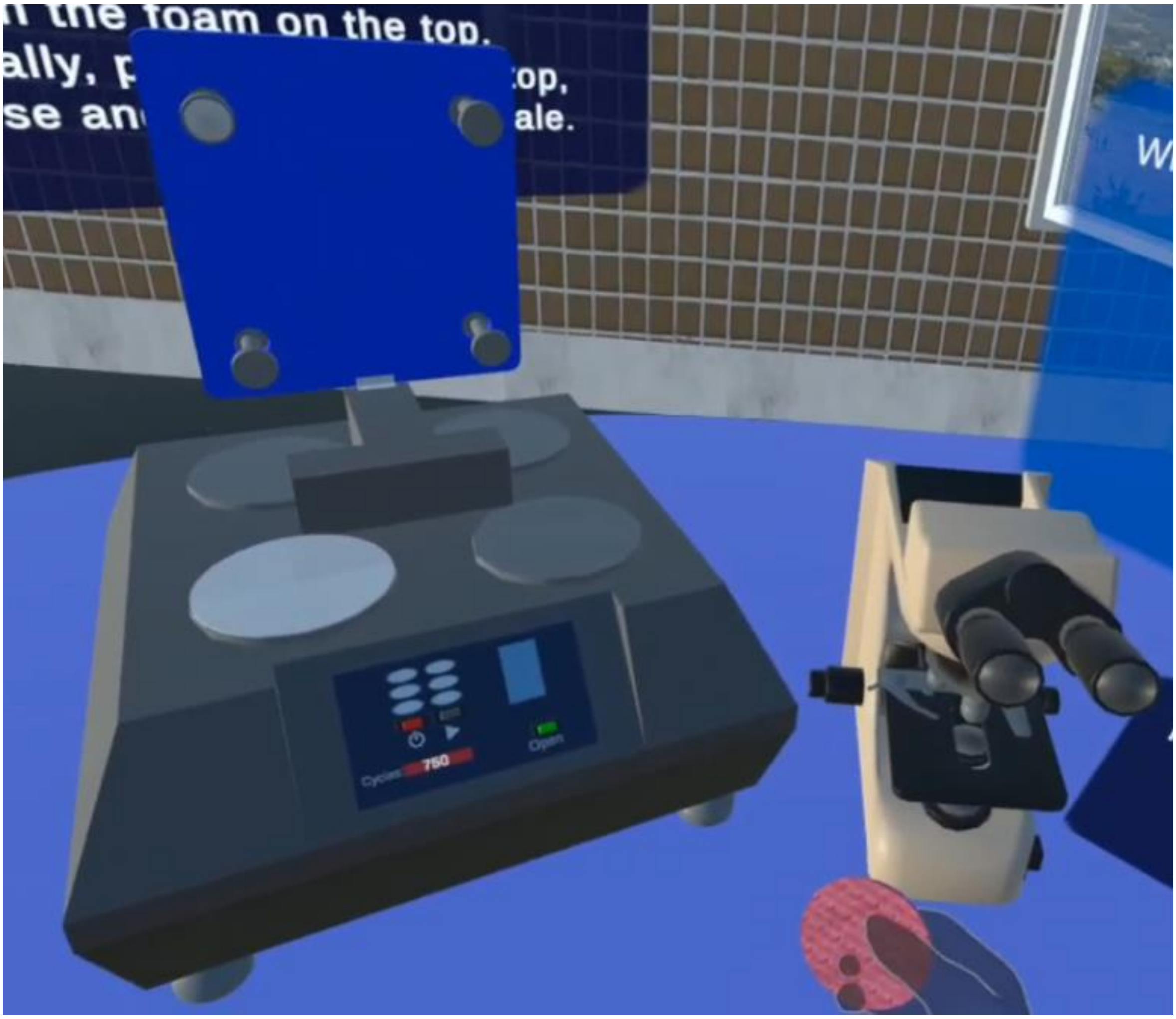


Figure 19. Martindale and microscope models created with Blender.

Meta Quest 2

This practically made Meta Quest 2 the primary VR headset to use with CircutexVR, as it features an untethered high-resolution display, along with hand tracking that can be used without any hassle. It is these features that make Meta Quest 2 an ideal platform for educational VR, enabling students to use a virtual laboratory without the need for sensors or external hardware. Critical to such a range of educational setups—where, ideally, students should be able to have access to CircutexVR in their remote learning setups—is the ease of portability and usability of the headset. Meta Quest 2's hardware optimization has been implemented with Unity 3D integration to make sure it runs with flawless operation in offering a gratifying experience to CircutexVR's users. In simple words, the technology stack of CircutexVR includes Unity 3D, C#, Blender, and Meta Quest 2, meaning that these are the technologies employed in making it possible for people to receive an interactive, immersive, and educative experience in a virtual reality environment. These tools and technologies are chosen and integrated very thoroughly, ensuring that CircutexVR will provide—or even overachieve—the educational goals aimed at by the CircuTex project and thus will provide a new, effective sustainability education tool in the ambit of sustainability education on fibrous composites and technical textiles.

4.3 Development stages

This section of the document provides a comprehensive overview of the practical case's content. It delves into the setup, the visual depiction of the virtual environment, and the various experiments and user experiences within the application. Additionally, I will touch upon some notable aspects of implementing experiment features, although I will not delve extensively into this area due to the intricate scripting and components involved in each experiment. Instead, the primary focus will be on elucidating the user's anticipated experience and the tasks expected to be performed in each experiment.

4.3.1 Project setup

Whole setup of the project was carefully scripted in Unity, especially 2021.3.2f1. Thus, this version was used because it's stable and compatible with the various VR development tools used, ensuring the fluent workflow in the integration of the different needed functionality for the project. The process included detailed setup of essential plugins and packages critical to optimization of VR environment tailored for educational purposes.

Oculus Interaction Toolkit was one of the cornerstones of this setup—a full suite of tools that aids creators in building interactive VR content. It helps increase the interaction capability of the user inside the CircutexVR application and greatly supports several functions such as hand tracking, controller input, and complex interaction models that are necessary for the simulation to be realistic. This integration enabled a coherent use of both intuitive controls and interaction mechanisms key in educational VR settings, where user engagement or interaction fidelity strongly influences the learning outcome.

Finally, many other Unity packages were imported into the project that provided support and augmentation for the Oculus Interaction Toolkit. These included physics packages for natural, realistic interaction with objects, rendering packages for proper visual output and high-quality visual output, and utility packages designed to smoothen the development process for developers in terms of debugging and performance optimization. Each of them was chosen to make a step towards a consistent and applicable VR educational environment, followed by all technical details matching the learning aims of the project.

This also meant that Unity was configured, and that supporting packages, like Oculus Interaction Toolkit, were added; but it formed a concrete base from where further development on CircutexVR could be done. This allowed for an extremely high level of interactivity and immersion, ensuring that the virtual laboratory simulations presented by the VLab were accessible and effective for learners grappling with complex topics in fibrous composites and technical textiles. By the end of the development phase during which such will be used to develop detailed, interactive, and educational VR experiences, the careful set-up of the system was essential preparation.

4.3.2 Virtual environment

In the initial stages of developing CircutexVR, ProBuilder, a tool that allows developers to build, edit, and texture 3D models directly within the Unity editor, was chosen to simplify the construction of the virtual environment, which included modelling the high-fidelity representations of laboratories like those at UPV. The walls (Figure 20), ceiling, and floor were initially created as a cube, which I then extruded using this tool until it matched the form of the actual lab. The walls are composed of four parts: starting from the bottom, there is a protruding base of white marble, followed by brown tiles that are the exact replicas of those at UPV because I photographed them and used that photo as a texture for this part of the wall, then a protruding wooden frame, and finally a white base that extends up to the ceiling. However, the application of textures in ProBuilder introduced challenges due to the straightforward design approach and my primary focus on coding rather than complex artistic modelling or texturing.

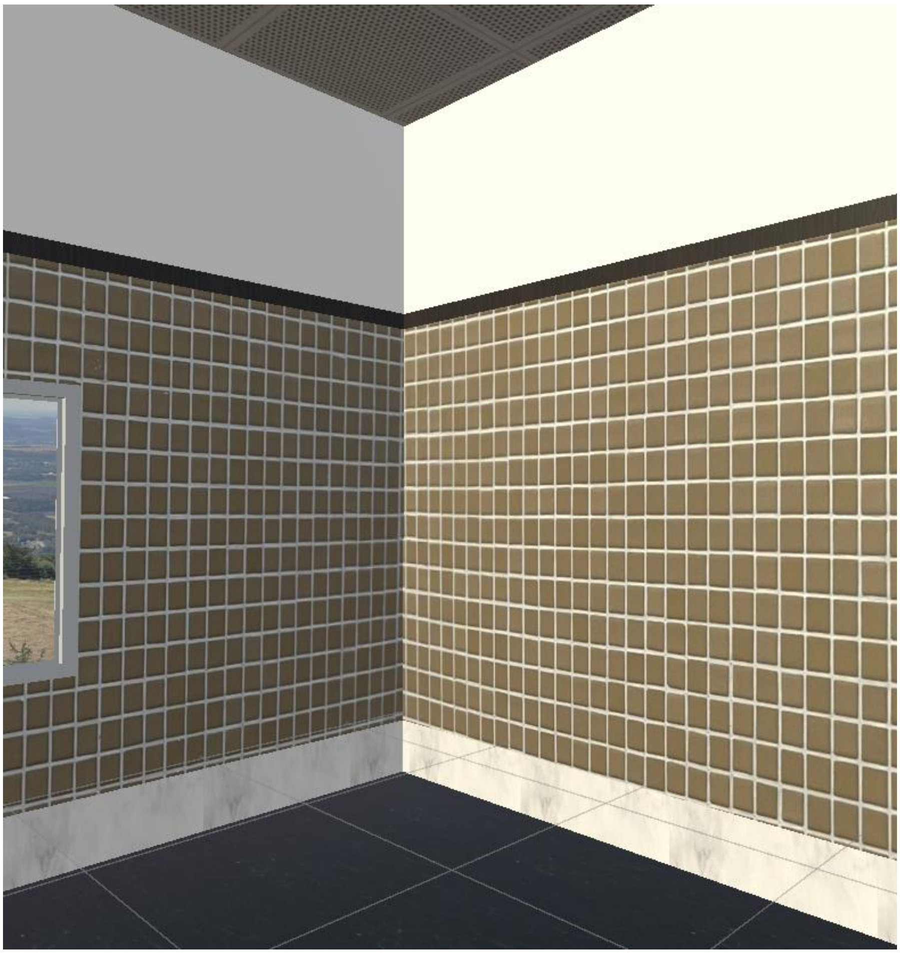


Figure 20. Wall of the laboratory.

The texturing process began with UV mapping, where each face of the 3D model was linked to a specific section of a 2D image. This step was crucial to ensure that textures wrapped correctly around the 3D structures. Once UV maps were established, textures might require simple adjustments such as scaling, rotating, or translating to align properly with the model's features. ProBuilder's tools facilitated these adjustments directly within the editor, which was particularly useful given my coding background and limited experience in detailed artistic modelling.

Ensuring that textures appeared seamless across different parts of the model was a challenge, especially in a virtual environment where users can examine surfaces up close. To address this, I used basic seamless texture patterns and made simple adjustments to UV edges to help textures blend together and avoid visible seams.

After aligning and adjusting textures, basic materials referencing these textures were applied to the model surfaces. At this stage of development, the focus was on maintaining a functional and visually coherent environment rather than enhancing it with complex properties like shininess, transparency, or bump mapping. My primary role as a coder, rather than a designer or modeler, meant that the artistic aspects of the environment were less elaborate, prioritizing functionality and the implementation of the simulator's features.

The modelling of the environment (Figure 21) was one of the first tasks in the project, which is why tools like Blender were not utilized at this stage—I simply did not possess the requisite knowledge or skills in more advanced 3D modelling techniques at the time.

By managing the texturing process with a straightforward approach, I ensured that the virtual environment was visually coherent and functionally effective. This careful attention to textural detail, even without advanced artistic input, supported educational outcomes by providing a realistic and familiar environment, enhancing both the usability and educational impact of CircutexVR. This design choice reflects the project's early developmental phase and my focus on creating a robust educational tool as a coder. This becomes an effective architectural change to ensure easy reach to all the vital materials and equipment required for proper unbroken learning in a smooth flow. One of the main goals of this kind of an approach is to enhance the educational interactivity and usability of the experience by placing the interactive elements in one spot that is highly accessible. This caring design links well with the educational aims of the project, which aims at creating a fluid and immersing learning environment in which the students may participate meaningfully to take on the content and practice.

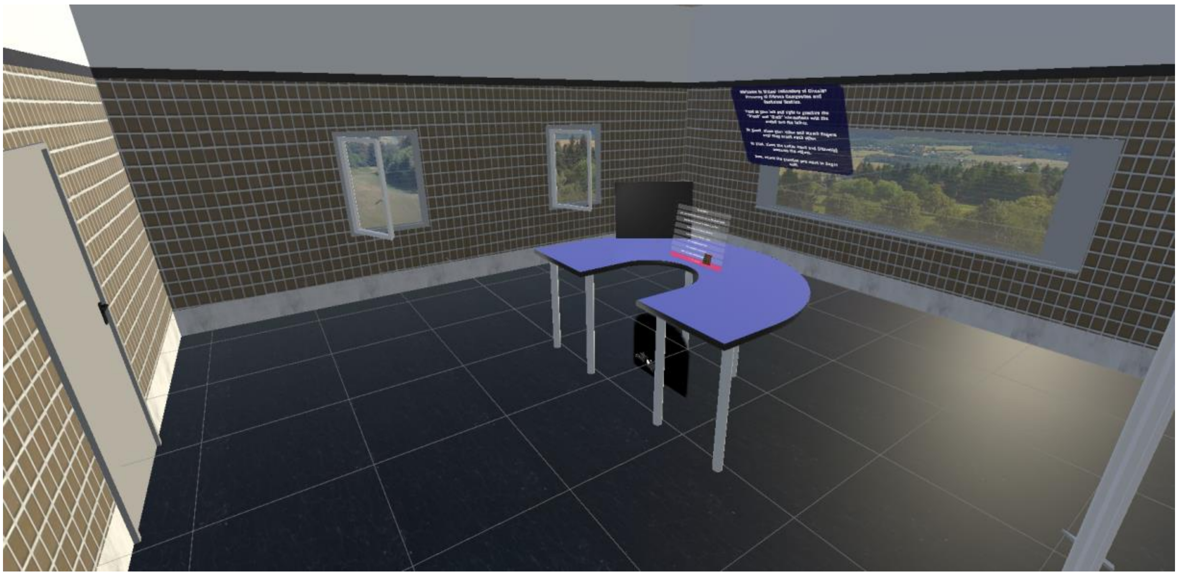


Figure 21. Virtual environment of CircutexVR.

The idea was to have, in the beginning, a real laboratory UPV scenario that users might need to move around and manipulate with all the objects, using Meta Quest 2 controllers for the interaction. The original design called for traditional free-roam VR, wherein users would look around the virtual environment by use of the joysticks on the controllers. This was seen to provide an authentic experience closely mimicking physical movement and exploration that was part of a real laboratory.

For most participants, this was their first exposure to virtual reality, and the majority struggled with the learning curve in the first phase of user testing, which is human. Firstly, the controllers were said to be not intuitive and didn't help users interact easily with the educational content. The users, left to find their way in the virtual lab on their own using joystick controls, suffered nausea and disorientation; in some cases, dizziness resulted from only minutes of interaction.

Therefore, with these challenges in mind, a design strategy of changing the interaction model to a more user-friendly environment, especially for new users to virtual reality, was placed. The environment was changed into a stationary setup, removing the need for moving in the space. Thus, in place of the random motion in the lab, the users were placed along a semi-circular table at one fixed centre in such a way that the required apparatuses and experimental setups were just one at half rotation away.

At the same time, the traditional VR controllers got replaced by a system that allows tracking of hands. It is a paradigm shift, one that leverages our intuitive way of using our hands—a method all users are naturally better with. Introducing the technology of hand tracking in CircutexVR would enable the subject to interact within the virtual space like natural or real surroundings with gestures and movements that mirror reality.

This change served to not only make the VR controllers less of a learning curve but also significantly reduced the physical discomfort felt by the users, thus tremendously improving the access and learning effectivity of the program. Such customizations have been very essential for changing the virtual environment and mechanisms of virtual interaction of CircutexVR into a more inclusive and user-friendly educational apparatus. Thanks to its intuitive design and user comfort, it makes sure that the student is fully engaged in the learning experience without the usability barriers typical for complicated VR navigation and control systems.

4.3.3 Experiments developed

Main menu

The solidly built main menu that will guide through the variety of interactive experiments in an intuitive way is in the core of the CircutexVR educational platform. The virtual laboratory menu (Figure 22) opens the door to a suite of comprehensive experiments tailor-made for learning the principles of Circular Economy in Fibrous Composites and Technical Textiles. User-friendly: The main design of the menu is very user-friendly for the users to move around and interact with the content provided, be they novices or very experienced VR users.

The main menu even includes a gamified set of sample objects egging you on to practice basic VR interactions like grabbing and pinching. These objects are designed so that they replicate the feedback and the dynamics of manipulation experienced in real-world laboratory settings, providing a first-person experiential learning environment. This is an important practice module since this will be the surest way by which the users may get acquainted with all the core interaction techniques, which will be very important to them for conducting the virtual experiments.

To further facilitate learning, the main menu is designed with an illustrative tutorial in the form of an embedded video in the virtual environment. In that tutorial, the user learns how to grab and pinch items in the actions very clearly and concisely offered for interaction. Being able to watch the video in the VR setting bridges the gap between this concept of interaction and its application within the virtual laboratory to a much easier ride for the user.

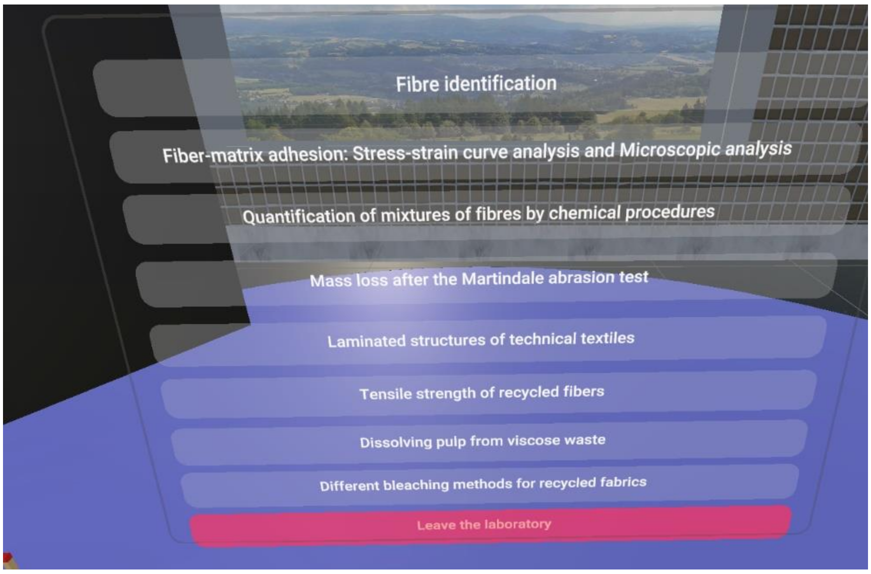


Figure 22. Main menu buttons of the simulator

The menu buttons used in CircutexVR are sourced from the Oculus Interaction Toolkit in Unity, specifically designed to facilitate user interaction through a realistic and intuitive interface. This toolkit allows the user to activate buttons by simply pressing them with their index finger, closely mimicking real-world interactions.

The creation process of this menu involved an in-depth study of the Oculus Interaction Toolkit to utilize its pre-built assets effectively. Each button was meticulously configured to trigger a scene change through a fading animation that had been set up in advance. This ensures a seamless transition between different parts of the virtual lab, enhancing the user experience and engagement.

There are extensive parameters available for each button, including colour changes when it is not pressed and when it is activated, and the specific interaction dynamics such as the allowable distance between the button and the index finger required for activation, and how far the button moves when pressed. Adjusting these parameters was essential to achieve the desired functionality, ensuring that the buttons not only respond appropriately to user interactions but also fit seamlessly into the overall design of the VR environment.

Practice 1: Fibre identification

The original idea of the Fiber Identification experiment is that it was conceptualized as a dual piece within CircutexVR—the 360-degree video with a parallel version as an interactive simulation. The video was framed in context by showcasing the performance of a student from Alcoy in a real laboratory setting. In retrospect, this component was later omitted from the final application as per project management feedback; however, the asset remains to be part of the comprehensive developmental assets used during projects. The interactive simulation offers the central part in the Fibre Identification experiment.

Upon entering the experiment, the user is presented with fibre samples, which remain unlabelled. The user is to identify the type of fibre present in the provided samples through testing that uncovers characteristic information specific to the type. So, the first task in the simulation is placing a sample of fibre under the virtual microscope for studying the microstructure. It is done to establish the unique physical attributes such as shape and texture.

After this, the user does the melting machine test (Figure 23), in which the fibre is exposed to heat to see characteristics of its melting. Different fibres showed reactions to such tests. Identification clues are hence provided. Another important test is the reagent bath test. Fibers are dipped in various chemical solutions during a reagent bath test, and they are observed for their chemical solubility. Interaction of each fibre with certain chemicals can substantially assist in the identification.

Lastly, in the pyrognostics test, a controlled flame is applied to the fibre sample in order to examine the kind of burning, the nature of smoke, the residue left and even the smell, giving an indication of its composition. The user collects data that would be used to deduce the type of fibres under consideration. This methodological approach helps in developing an understanding of properties and skills in analysing the deduction of fibres.

After doing all tests to the sample, the user is able to guess which type of fibre it is in the evaluation test, checking its own knowledge. There are several samples to practice in this experiment.

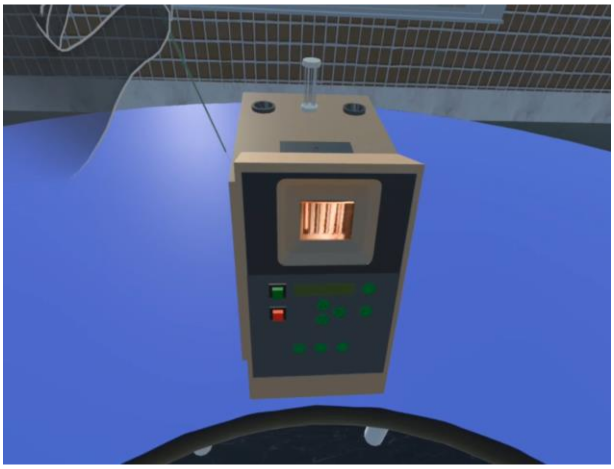
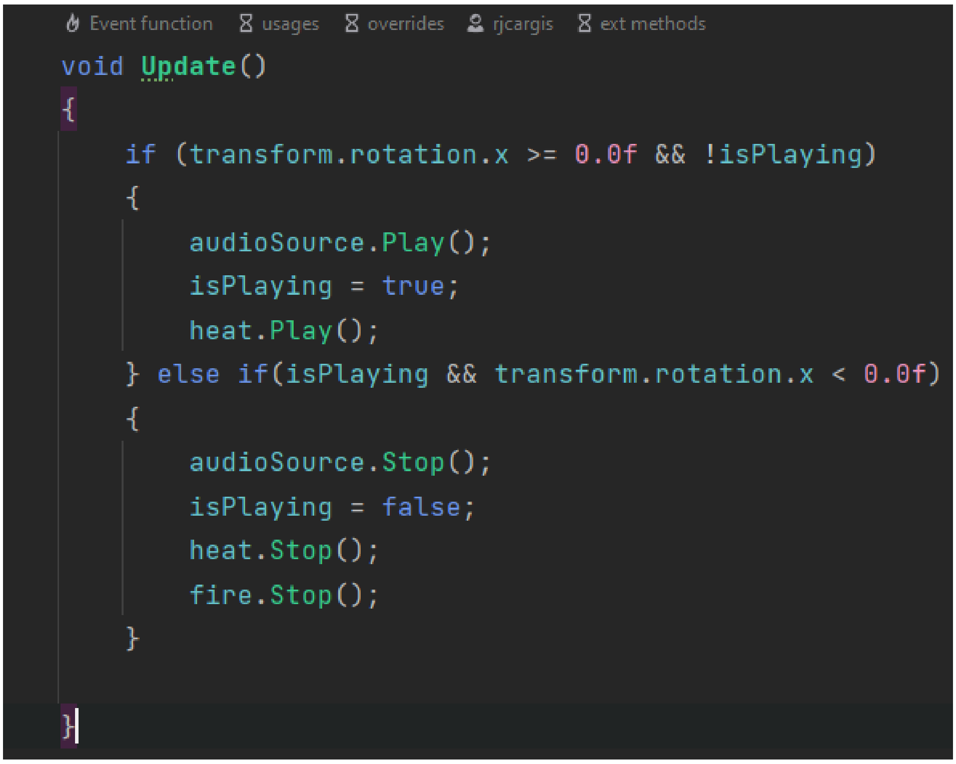


Figure 23. User placing the sample into the melting machine.

In this experiment and all the others, a virtual keyboard was implemented to allow users to take notes during the process. Utilizing Poke Interaction for key presses and a holographic screen where the user can visualize what they are typing, the keyboard was entirely developed by me. As such, it lacks the artistic touch that might be found in other applications, but functionality and immersion were the primary focus. I concentrated on making it intuitive, incorporating sound feedback for each keystroke, and ensuring it functioned flawlessly.

The most challenging part of this experiment was undoubtedly the pyrognostics test. For this test, I had to implement functionality for turning the wheel on a Bunsen burner using a component from the Oculus Interaction Toolkit that allows grabbing and rotating items around an axis, similar to how one might open a door. This was particularly tricky because the wheel, being a small element, is difficult to interact with for rotation using hand tracking. To resolve this, I added a small extension to the wheel, making it easier to grab and rotate. Once the wheel reaches a specific angle, a sound consistent with the gas particle effects emitted by the Bunsen burner is triggered (Figure 24).



```
void Update()
{
    if (transform.rotation.x >= 0.0f && !isPlaying)
    {
        audioSource.Play();
        isPlaying = true;
        heat.Play();
    } else if(isPlaying && transform.rotation.x < 0.0f)
    {
        audioSource.Stop();
        isPlaying = false;
        heat.Stop();
        fire.Stop();
    }

}
```

Figure 24. Code fragment of the Bunsen burner.

The burner interacts with a trigger when it comes into contact with the tip of a match (Figure 25), which lights up as soon as the user grabs it. The lighting of the match also operates with a particle effect. These particle effects are assets downloaded from the Unity Asset Store. All interactable elements in the simulator offer event capturers like "OnSelect", "OnMove", "OnUnselect", etc., which is how I added the necessary code to enable the match to ignite immediately upon being grabbed. This meticulous detail in the interaction design enriches the educational experience, engaging users in a realistic simulation that closely mimics actual laboratory procedures.

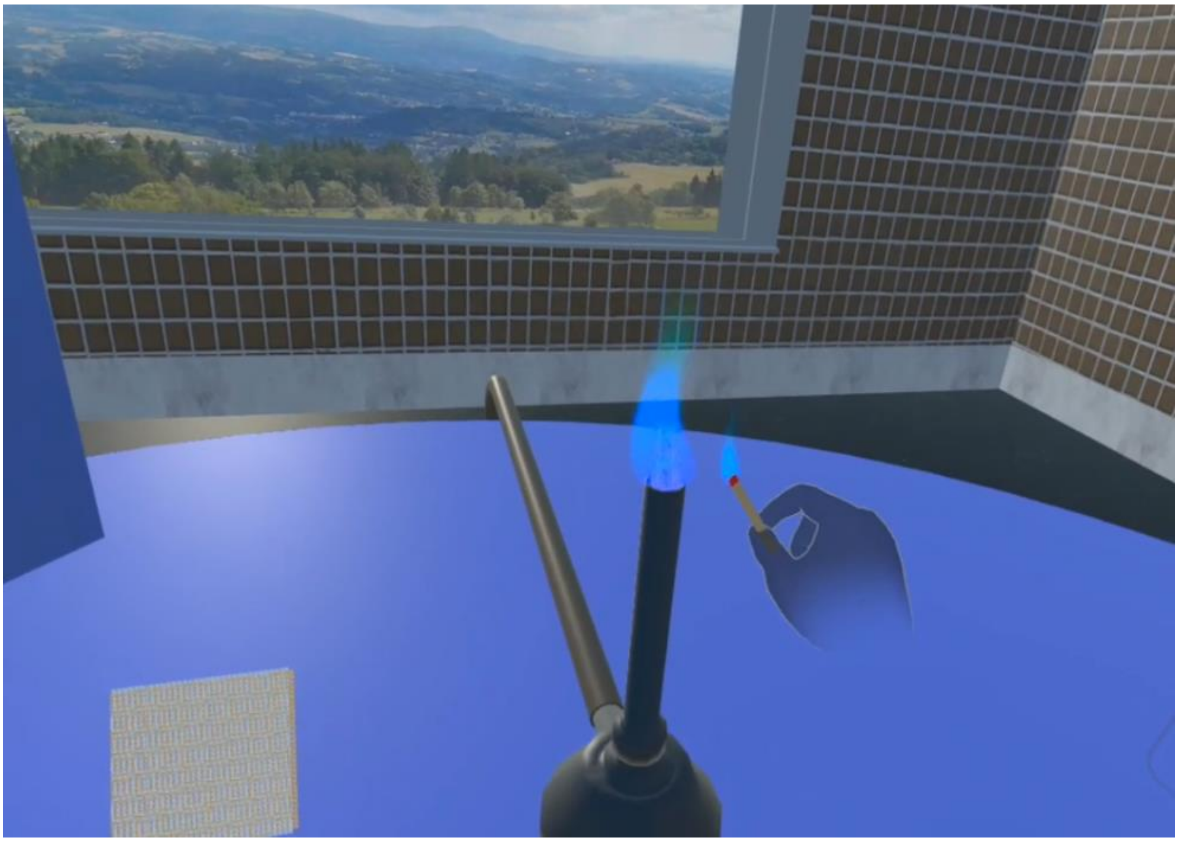


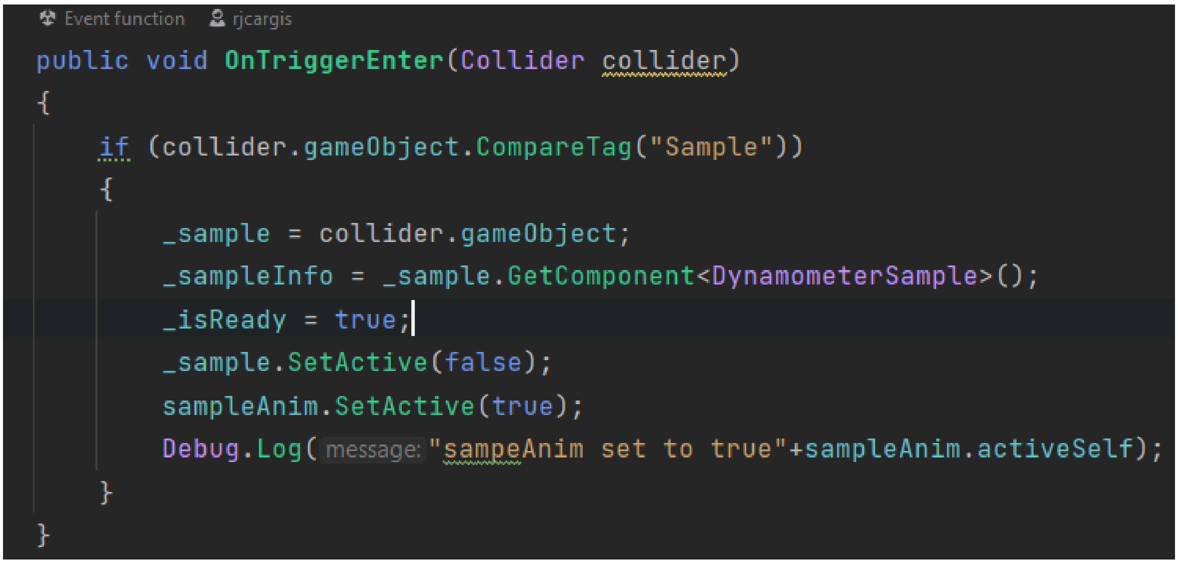
Figure 25. User starting the fire for the pyrognostics test.

Practice 2: Fibre-matrix adhesion: Stress-strain curve analysis and Microscopic analysis.

The fibre-matrix adhesion experiment is focused on the mechanical characteristics of composite materials through the study of stress-strain curves, backed with microscopic study. This experiment allows obtaining actual knowledge of how the fibres bind with their matrix, one of the most essential preconditions for applications in the area of materials science and engineering.

At the start of the experiment, the user is shown several unlabelled samples, each representing a different type of composite material whose adhesion properties are to be assessed. The user places a sample in the virtual environment on the display of the dynamometer and fixes it. After fixing, the user activates the dynamometer using a virtual button, mimicking real-world operations, and begins the measurement of mechanical properties. Tensile testing involves the dynamometer stretching the sample and recording the force applied, resulting in a graphical presentation of the material under stress in the form of a stress-strain curve.

The implementation of this experiment features a key aspect in the animation of the dynamometer interacting with the sample. When the user places the sample in the clamps, a script automatically makes the actual sample invisible and activates two copies of the sample (Figure 26). These copies act as the breaking sample animation. This approach ensures that during the animation, the user cannot interact with or re-grab the original sample, maintaining the integrity and realism of the experiment. Essentially, the user is viewing an animation of the dynamometer breaking a replica, not the original game object they initially interacted with (Figure 27).



```
public void OnTriggerEnter(Collider collider)
{
    if (collider.gameObject.CompareTag("Sample"))
    {
        _sample = collider.gameObject;
        _sampleInfo = _sample.GetComponent<DynamometerSample>();
        _isReady = true;
        _sample.SetActive(false);
        sampleAnim.SetActive(true);
        Debug.Log( message: "sampeAnim set to true"+sampleAnim.activeSelf);
    }
}
```

Figure 26. Code for placing the sample in the dynamometer.

Samples tested on the dynamometer provide the user with information on material strength and ductility. This hands-on experience with the dynamometer enables users to understand the basic principles of tensile testing and obtain concrete mechanical property data from various composites.

To conclude the experiment, users are directed to an evaluation test within the same sample selection interface. This test is designed to assess the user's understanding of the data collected and their ability to interpret this data. The evaluation consists of questions that require the user to analyse the stress-strain curves and microstructural images to determine, based on their mechanical properties, which of the samples shows delamination.

This experiment not only deepens the understanding of material properties but also allows the user to apply their analytic skills in full force, involving practical testing and assessment of theoretical knowledge at this point in the experimentation.

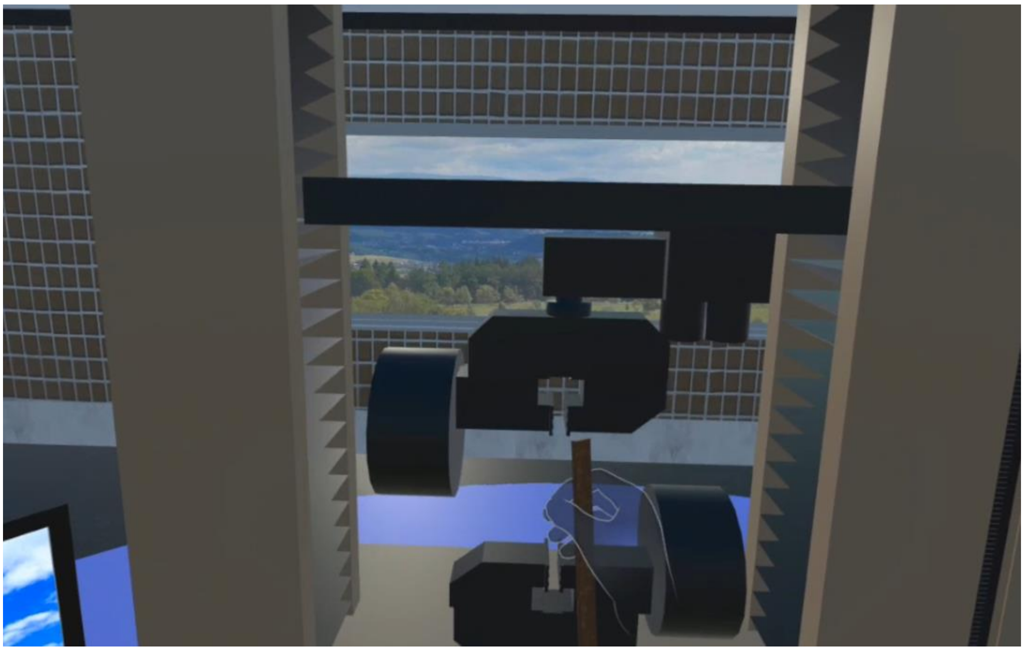


Figure 27. User placing the interactable sample on the dynamometer.

Practice 3: Quantification of mixtures of fibres by chemical procedures

The Quantification of Mixtures of Fibers experiment is designed to provide users with a detailed understanding of how to determine the composition of fabric mixtures through chemical procedures. This experiment allows users to apply practical chemistry skills in a virtual environment, mirroring the processes used in real-world textile laboratories.

In this practice, users begin by selecting one of four available samples, each labelled with two types of fabric. The primary goal is to determine the percentage composition of each fabric type in the selected sample. The procedure for achieving this is meticulously designed to mimic the steps a chemist would take in an actual lab setting.

The first step involves weighing the initial sample on a virtual laboratory scale (Figure 28), which features a trigger that when in contact with the sample, displays the associated weight on the screen. Users must carefully record this initial mass in the virtual notepad, crucial for the calculations later in the experiment.

Following the initial weighing, the user removes one type of fabric from the sample by placing it in a reagent bath designed to dissolve one fabric type without affecting the other. This critical step isolates one of the fabrics from the mixture, supported by an animation showing the sample being immersed and then becoming available again for the user to grab.

After the dissolution process, the sample is washed with water to remove any residual chemicals, which could affect the subsequent drying process and the final weighing. The user then transfers the washed sample into a special laboratory oven that the user can open and close as if it were a real door, preparing it for the final weighing.

Once the sample is dried, it is weighed again on the virtual scale. The new mass is recorded, and the user uses this data along with the initial mass to calculate the percentage composition of each fabric type. This calculation is done using a virtual calculator implemented similarly to the virtual keyboard but with the functionalities of a basic calculator.

The final step involves the user selecting the correct answer in an evaluation test, which offers six possible solutions. If any step of the procedure is performed incorrectly—for instance, if the sample is washed before the necessary chemical treatment—the mass obtained will be deliberately incorrect, leading to erroneous calculations and a failed evaluation. This aspect of the experiment emphasizes the importance of following proper chemical handling and processing techniques.

In this experiment, the key feature has been the weight of the sample, which plays an essential role in the completion of the experiment. As the user modifies the sample by immersing it in acid, water, or drying it in the oven, the weight changes as it would in real life. Therefore, if the user conducts any part of the experiment incorrectly, such as wetting it before acid treatment or drying then bathing it in water, the weight must reflect this so that if the user relies on this weight for calculations, the outcome will be erroneous, thus alerting the user to their mistake. This implementation required extensive coding and attention to detail to ensure each modification to the sample (acid, water, and oven) and the sequence of these modifications accurately affect the outcome.

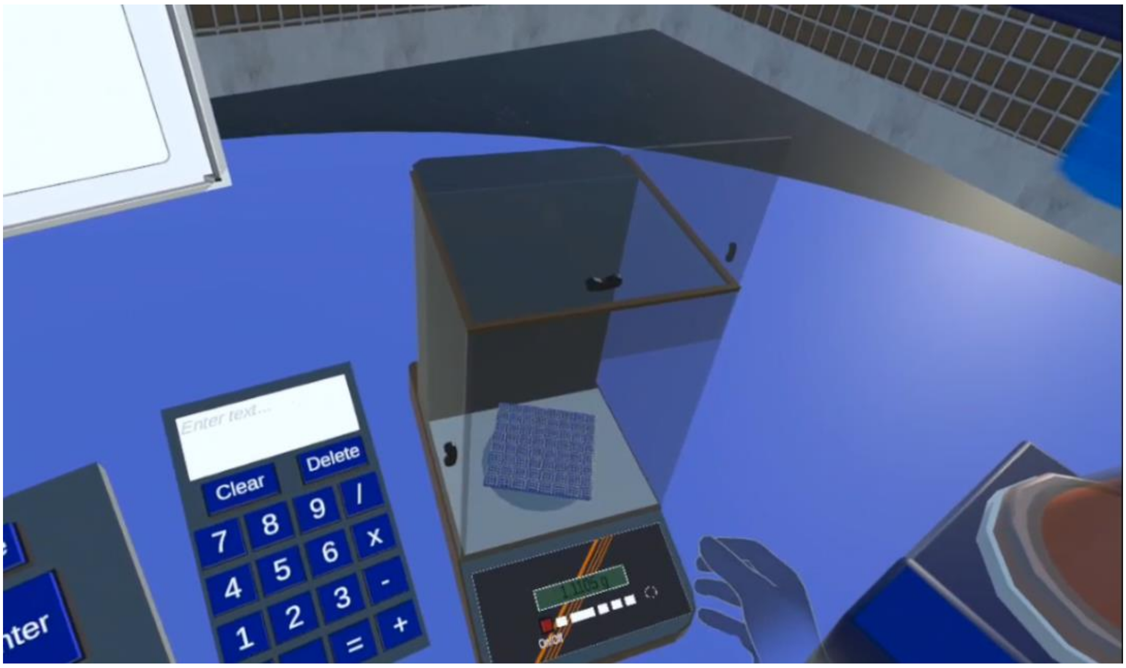


Figure 28. User weighing the sample with the scale.

Practice 4: Mass loss after the Martindale abrasion test.

This experiment (Figure 29) meticulously simulates the evaluation of fabric durability against abrasion, integrating complex virtual tools and interactions that replicate real-world textile testing procedures. The implementation of these virtual tools is central to achieving a realistic user experience.

Participants begin by selecting a fabric sample, each varying in material type which affects how it reacts under stress. The next crucial step involves the precise cutting of the sample using virtual cutters. These cutters are programmed with a detection system that recognizes gameobjects tagged as "Sample." An OnTriggerStay mechanism triggers a two-second animation that simulates cutting, resulting in the original square sample being replaced by two new gameobjects: a round sample and the excess material cut away, thus enhancing immersion and realism.

For examining the initial appearance of the fabric, a virtual microscope is used. In this implementation, participants must manually place the sample onto the microscope and activate it by pressing a button. If the sample is removed, the microscope deactivates, requiring reactivation for further examinations. This manual interaction emphasizes the hands-on nature of laboratory work.

The weight of the fabric sample is recorded on a virtual scale reused from previous experiments. This scale features a trigger that, upon contact with the sample, displays the associated weight, critical for subsequent calculations. Participants then place the fabric, along with foam and abrasive fabric, inside the Martindale machine. The Martindale machine's implementation is complex due to its capability to hold samples in four different compartments. Each compartment has a specific transform that secures the sample in place when positioned by the user. Managing the virtual reality elements that allow for the placement and removal of the sample posed significant challenges. These elements are temporarily disabled and then re-enabled when the sample is placed to ensure proper interaction without errors. The Martindale has also 3 buttons; one for turning it on, another for opening it, and another to start the abrasion, each of them having their own scripts.

The abrasion process in the Martindale machine is cyclic, pausing to allow for the examination and weighing of the fabric, which informs the participant of the wear incurred and measures the sample’s mass loss. After multiple cycles, simulating extended wear, the fabric is re-examined under the microscope.

To conclude the experiment, participants utilize a virtual calculator—implemented similarly to the virtual keyboard but with basic calculator functionalities—to analyse the data. They compare initial and final weights and assess visual wear on the fabric. The final part of the experiment involves an evaluation test with multiple-choice answers, testing the participant's understanding of the abrasion resistance of the fabric.

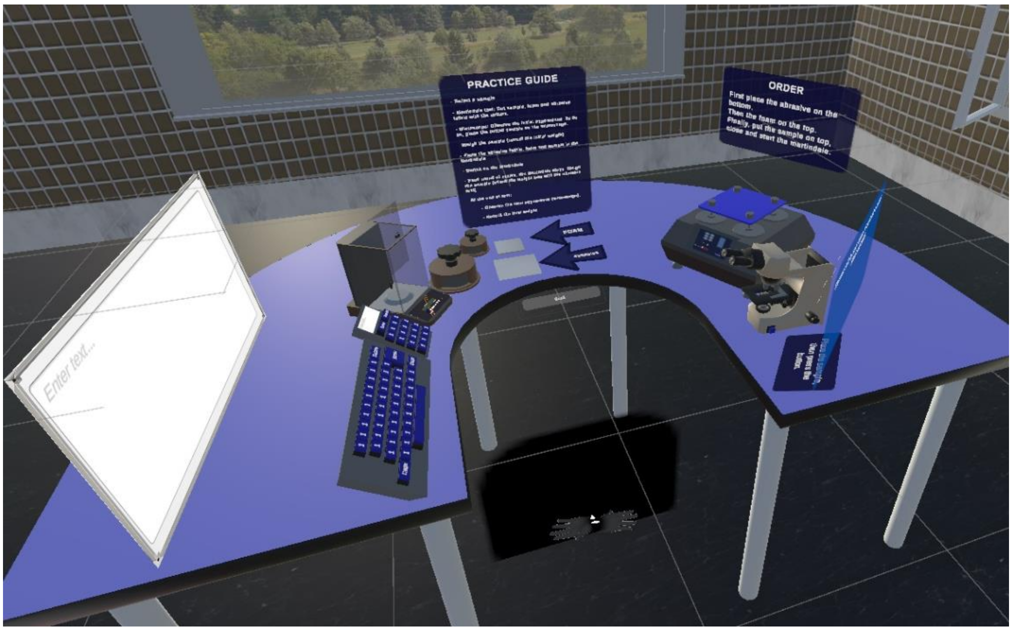


Figure 29. Martindale experiment scene.

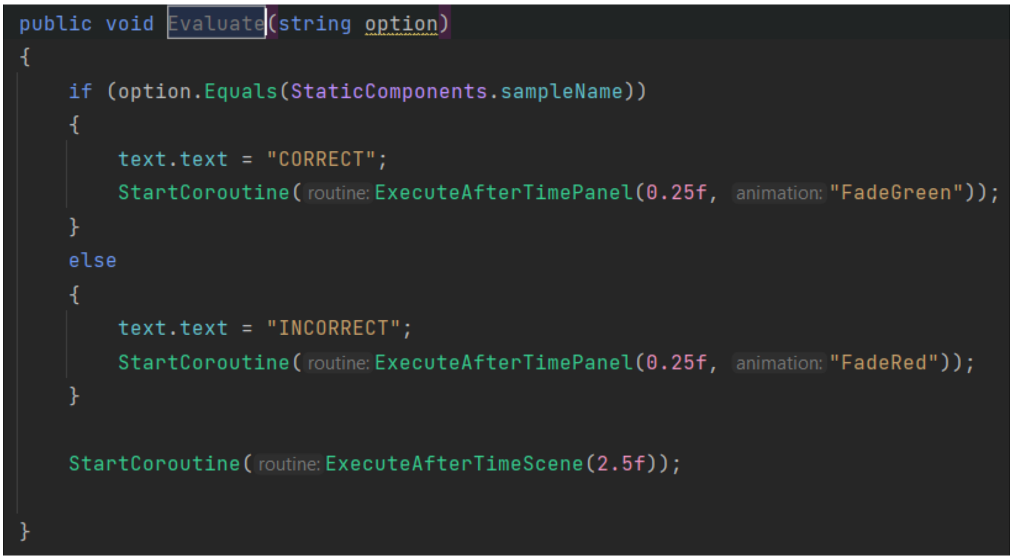
Practice 5: Laminated structures of technical textiles

In the Laminated Structures of Technical Textiles experiment, participants explore different textile manufacturing techniques by examining ten unique samples representing weaving, knitting, non-weaving, and braiding.

The process begins with participants selecting a sample to place under a virtual microscope. This detailed examination allows them to observe the intricate structural patterns that characterize each textile type. Based on their observations and knowledge, participants must identify the type of textile structure they are examining.

The experiment concludes with an evaluation test where participants verify their observations by selecting the correct structure type for the sample they analysed. This test assesses their ability to accurately categorize textile structures, reinforcing their understanding of material properties and enhancing their analytical skills.

This experiment was quite easy to implement because all functionalities were already implemented in previous experiments, so they were reused and modified accordingly to this experiment. When the user selects a sample, there is a public static variable that changes its name to the name of the correct answer of the test. When the user selects a test answer, it compares its value with the one stored in the static variable (Figure 30), and if they match, then its correct and executes the “correct” animation or the “incorrect” animation otherwise. Then it brings the user back to the sample selection to keep practicing.



```
public void Evaluate(string option)
{
    if (option.Equals(StaticComponents.sampleName))
    {
        text.text = "CORRECT";
        StartCoroutine( routine: ExecuteAfterTimePanel(0.25f,  animation: "FadeGreen"));
    }
    else
    {
        text.text = "INCORRECT";
        StartCoroutine( routine: ExecuteAfterTimePanel(0.25f,  animation: "FadeRed"));
    }

    StartCoroutine( routine: ExecuteAfterTimeScene(2.5f));

}
```

Figure 30. Evaluation test piece of code that compares the answer selected by the user with the correct answer.

Practice 6: Tensile strength of recycled fibres

The Tensile Strength of Recycled Fibers experiment is a comprehensive module that tests the mechanical properties of fibres under different conditions. This practice is designed to be particularly detailed and iterative, offering participants a deep dive into the characteristics of recycled fibres.

At the beginning of the experiment, participants find themselves in a virtual environment where they can choose from three different fibre samples. Each selection is part of a systematic process that participants must complete twice—once under dry conditions (Figure 31) and once under wet conditions, totalling six tests. This dual condition testing is reflected in the interface with a hologram indicator displaying "Progress 0/6," which updates as the participant advances through the experiment.

The procedure for each test involves placing the selected fibre sample into the clamps of a virtual dynamometer. This machine measures the tensile strength of the fibres, providing real-time data on how much force each fibre can withstand before breaking. After each dynamometer test, the virtual computer gives feedback on the performance of the fibre, including its tenacity and elongation at the break, based on the fibber's linear density.

Participants are required to use this data to calculate specific properties of the fibre, such as tenacity and elongation. Correct calculations allow the participant to progress to the next stage of the experiment—testing the same fibre under wet conditions. This iterative process, where each sample is tested twice under different conditions, challenges participants to understand how moisture affects the mechanical properties of recycled fibres.

Upon successfully completing all six tests, participants unlock the final test of the practice. This test is a culmination of the entire experiment, requiring participants to accurately answer questions based on their observations and calculations from previous tests. Passing this final test confirms the participant's comprehensive understanding of the tensile strength and behaviour of recycled fibres under varying conditions.

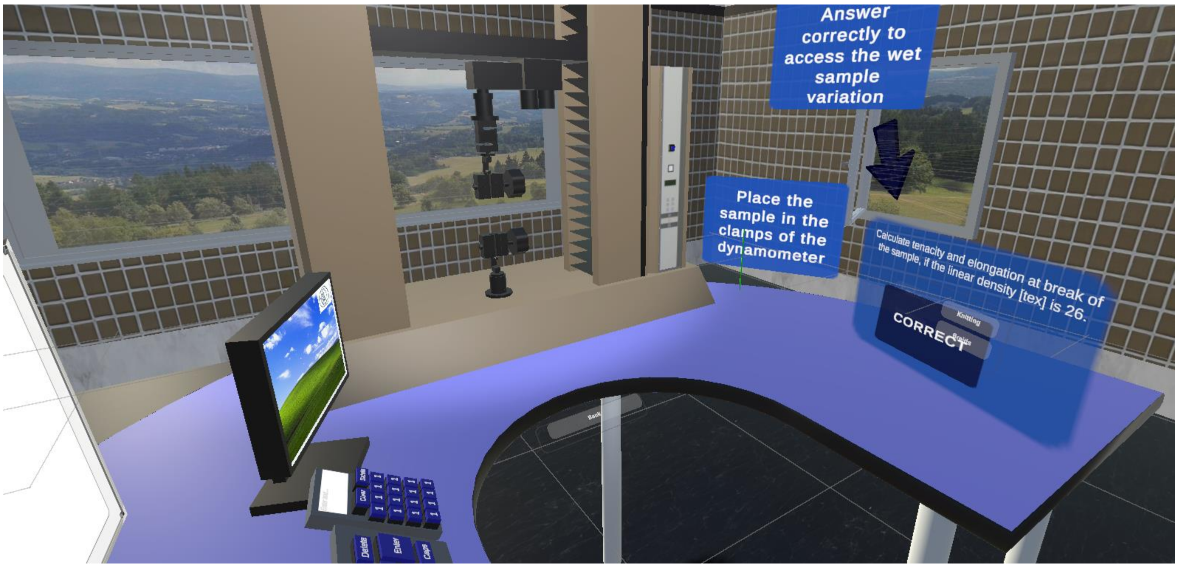


Figure 31. Practice 6 dry sample scene.

Practice 7: Dissolving pulp from viscose waste

This experiment (Figure 32) introduces participants to the process of recycling viscose materials, a crucial aspect of sustainable textile manufacturing. The implementation of interactive tools, particularly the scissors, posed significant challenges due to the limitations of hand tracking.

At the beginning of the experiment, participants are provided with virtual scissors, the implementation of which proved to be the most contentious aspect of the experiment. Simulating the intricate movements of scissors in VR with limited interaction options—pinch, grab, and poke—was particularly challenging. After careful consideration, I opted to animate the scissors to open and close whenever the user grabs them, providing a practical solution to the interaction dilemma.

The first task involves using these virtual scissors to cut a provided viscose sample into strips, mirroring the initial stage of the recycling process where materials are broken down for efficient processing. The accuracy of this preparation is crucial to ensure consistent test conditions.

Subsequently, participants immerse the strips into a designated solvent within the virtual environment to observe the solubility of viscose under specific conditions. This step is pivotal in showcasing the chemical properties of viscose and its behaviour during recycling and repurposing processes. Participants closely observe any changes in the viscose strips, such as dissolution or structural breakdown, noting their observations for later evaluation.

Following the observation phase, participants transition to the evaluation segment of the practice, where questions related to their observations and the chemical processes involved are presented on a holographic test interface. This comprehensive approach not only enhances understanding of viscose recycling but also sharpens analytical skills, offering a holistic learning experience in sustainable textile manufacturing.

- Cut the sample
- Put it in the solvent
- See the result
- Answer the questions on your right

The starting color of the mixture is dark brown.

Figure 32. Practice 7 scene.

Practice 8: Different bleaching methods for recycled fabrics.

The Different Bleaching Methods for Recycled Fabrics experiment in CircutexVR (Figure 33) delves into the comparative analysis of chemical bleaching agents on textile materials. This exercise is structured to provide participants with hands-on experience in applying different bleaching techniques and observing their effects on fabric properties.

In this practice, participants begin by selecting one of the available fabric samples. Each sample must be thoroughly examined under a microscope to document its initial condition and characteristics. This initial observation is critical as it provides a baseline against which the effects of the bleaching agents can be measured.

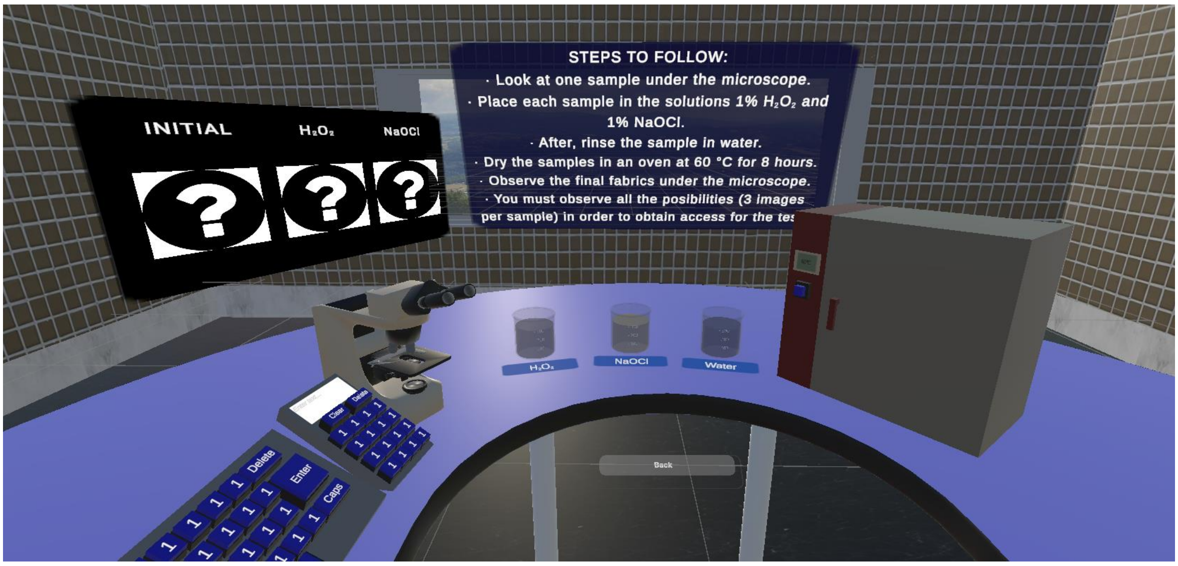
Following the initial microscopic examination, the experiment involves two replicas of the same sample, each subjected to a different bleaching agent—hydrogen peroxide (H_2O_2) and sodium hypochlorite ($NaOCl$). These agents are commonly used in textile processing and offer distinct bleaching effects. The participant places each fabric replica into a bath of one of the two chemicals, ensuring that the samples are fully immersed to allow the chemicals to act effectively.

After the bleaching process, each sample is thoroughly rinsed with water to remove any residual chemicals. This step is crucial to prevent further chemical reactions during the drying process. The samples are then placed in a virtual oven to dry, preparing them for re-examination.

Once dried, the samples are again observed under the microscope. This second observation allows participants to assess the changes in fabric colour, texture, and integrity post-bleaching. Participants compare these outcomes with the initial observations to determine the effectiveness and impact of each bleaching agent on the recycled fabric.

The process is repeated for each of the remaining samples, with participants required to complete all experimental steps for all samples. This repetitive approach ensures a comprehensive understanding of how different bleaching agents affect various fabric types.

Upon completing the experiments with all samples and their outcomes, participants gain access to the final test. This test evaluates their ability to understand and analyse the results of different bleaching methods, challenging them to apply their knowledge in practical and theoretical contexts.



STEPS TO FOLLOW:

· Look at one sample under the microscope.

· Place each sample in the solutions 1% H_2O_2 and 1% NaOCl.

· After, rinse the sample in water.

· Dry the samples in an oven at 60 °C for 8 hours.

· Observe the final fabrics under the microscope.

· You must observe all the posibilities (3 images per sample) in order to obtain access for the tes

Figure 33. Practice 8 scene.

4.4 Implementation for Educational Purposes

CircutexVR is designed to mimic a real-life laboratory, making it easier for students to learn and practice materials science in a virtual reality setting. This approach makes learning feel more real and hands-on, bridging the gap between classroom theory and actual lab work.

One of the key features of CircutexVR is its use of hand tracking technology. Instead of using traditional VR controllers, which can be unfamiliar and tricky for some users, CircutexVR allows students to use their own hands just as they would in a real lab. This natural way of interacting with the environment reduces the time it takes to learn the system, allowing students to focus more on what they are learning rather than how to use the technology.

Throughout the development of CircutexVR, textile experts from the Universitat Politècnica de València were involved to make sure that all experiments were accurate and realistic. Their expertise ensured that the simulations are up to professional standards and truly beneficial for students learning about textiles.

CircutexVR brings a new dimension to learning by allowing students to engage directly with materials and processes they're studying. This direct engagement helps make complex concepts easier to understand and remember. In a virtual environment, students can experiment safely and freely, making mistakes and learning from them without any real-world risks.

4.5 Training Participants

The CircutexVR project has seen extensive engagement from a diverse group of participants across educational and professional settings (Figure 34), significantly enriching both the development and dissemination of the platform. The core of this participation started with the pilot testing phase, which involved a total of 194 students from four different institutions. These institutions included the University of Oradea, Universitat Politècnica de València, University of West Attica, and Kaunas University of Technology, contributing 27, 40, 91, and 36 students respectively.

Figure 34. Project partners testing CircutexVR

These students participated in comprehensive testing sessions that provided crucial feedback on the usability and educational effectiveness of the VR platform. The practical sessions allowed students to engage with simulated textile experiments that mirrored real-world laboratory tasks, offering them a hands-on approach to learning that is rarely available in conventional classroom settings. This phase was critical not only for assessing the intuitive aspects of the software but also for validating its educational potential in delivering complex textile education in a virtual format.

The insights gained from these pilot tests were instrumental in refining the CircutexVR interface and functionalities, ensuring that the system was both user-friendly and aligned with actual laboratory procedures. The feedback helped identify key areas for improvement such as navigation ease, interaction realism, and educational content accuracy, which were subsequently addressed to enhance the overall user experience.

This direct involvement of students in the testing phase ensured that CircutexVR developed as a robust educational tool tailored to the needs and expectations of its primary users. It also provided an early indication of how effectively virtual reality could be integrated into textile education, setting the stage for broader academic application and acceptance.

4.6 Practical Testing and Usage

Following the pilot testing, CircutexVR was introduced to a broader academic audience through its presentation at various significant international conferences and workshops. This phase of practical testing and usage involved not just students, but also academic staff from various universities who participated in events where CircutexVR was showcased.

Key among these events were the WINTEX project meetings and the T-CREPE project mobility visits, where CircutexVR was presented in detail to the attendees. These presentations were pivotal as they introduced the project to potential academic and industry partners, gathering valuable feedback which helped further refine the platform. For instance, during the T-CREPE project mobility visit to UNIWA, CircutexVR was demonstrated to a group of students from the University of Ghent, who participated in various activities. This interaction provided an excellent opportunity to showcase the practical applications of CircutexVR and to discuss its integration into textile education curriculums.

Moreover, the Erasmus Days at the UPV-Alcoy Campus and various international conferences such as "Sustainable Fashion: Textiles of the Future" played a crucial role in testing the educational theories underpinning CircutexVR. These events allowed for the demonstration of CircutexVR's capabilities in real-time to a diverse audience, including educators, researchers, and industry professionals, providing further validation of its effectiveness as a teaching tool.

These practical tests and usage scenarios were essential for demonstrating the real-world applicability of CircutexVR, proving its worth beyond the initial development stages and highlighting its potential to revolutionize textile education through advanced VR technology.

4.7 Feedback Collection and Evaluation

The final phase involved rigorous feedback collection and evaluation (Table 1), which was critical in the continuous improvement of CircutexVR. This feedback was not only gathered from students who directly interacted with the platform but also from academic professionals and industry experts who encountered CircutexVR at various academic and industry events.

Table 1. Feedback from the project partners.

Experiment	Guide/VR Experiment	Improvement	Comments
Fibre identification-Optical Microscope	VR Experiment	Microscope images	Improvement of the quality of some microscope images. They become pixelated and difficult to identify.
Mass loss after the Martindale abrasion test	VR Experiment	Martindale equipment	Not fully supported on the table
Mass loss after the Martindale abrasion test	VR Experiment	Practice instructions	There is no indication that in order to look at the sample under the microscope, it must first be cut with the cutter.
All experiments	VR Experiment	General improvement	Further explanation of some steps
All experiments	VR Experiment	General improvement	how to go backwards in some scenes. not intuitive
Mass loss after the Martindale abrasion test	VR Experiment	Practice instructions	The instructions do not indicate which cutter should be used to cut each fabric (abrasive, foam and sample).
Mass loss after the Martindale abrasion test	VR Experiment	Practice instructions	There should be a sign indicating the abrasive fabric, sample and foam.
Different bleaching methods for recycled fabrics	VR Experiment	Practice instructions	Indication that in some experiments when you finish the essays, you must now answer the questions,
Tensile strength of recycled fibers	VR Experiment	Practice instructions	Indication that in some experiments when you finish the essays, you must now answer the questions,
Dissolving pulp from viscose waste	VR Experiment	Practice instructions	Indication that in some experiments when you finish the essays, you must now answer the questions,
Tensile strength of recycled fibers	VR Experiment	Practice instructions	Indication: you must perform the dry and wet test to pass to the tests and finalize the practice.
All experiments	VR Experiment	General improvement	Show you which tests you have already done (per user)
All experiments	VR Experiment	General improvement	Although the guides explain and help you perform the experiment, you cannot read the guidelines and wear the glasses at the same time, so the instructions are important. Possibility to include a summary of the objective or what you have to do in practice.
Mass loss after the Martindale abrasion test	VR Experiment	Practice instructions	It is difficult to place the sample in some equipment (microscope, Martindale,.).
Mass loss after the Martindale abrasion test	VR Experiment	Practice instructions	Instructions for placing abrasive cloth, sample and foam in the Martindale

All experiments	All experiments	All experiments	More sounds, more immersive feeling
Fibre identification-Pirognostic test	VR Experiment	Bunsen burner	To burn the sample
Fibre identification-Pirognostic test	VR Experiment	Bunsen burner	Instructions on how to light the Bunsen burner
All experiments	VR Experiments	Practice improvement	More explanations for the steps that must be followed for some of the experiments
Identification of textile structures	VR Experiments	Practice improvement	Very difficult to insert the sample in the microscope
Fiber identification. Pirognostic tests	VR Experiments	Practice improvement	On the pyrognostics test - it would be very interesting to see how the samples are burning

The feedback mechanisms were structured to capture detailed insights into every aspect of CircutexVR's functionality, from its educational content and user interface to its technical reliability and application in real-world educational settings. This comprehensive feedback has been instrumental in refining CircutexVR, with particular focus on enhancing its educational content and user interface to better meet the needs of both students and educators.

Moreover, the ongoing evaluations (Figure 35) have provided a deeper understanding of how virtual reality can be effectively integrated into textile education curricula at various educational levels. This has involved assessing the long-term impact of CircutexVR on learning outcomes, student engagement, and the acquisition of practical skills, which are essential for students pursuing careers in textile sciences.

By continuously engaging with a broad spectrum of participants and rigorously evaluating their feedback, the CircutexVR app has not only validated its approach through real-world testing but also expanded its impact by incorporating a wide range of perspectives and expertise. This comprehensive participant involvement and diligent evaluation process have ensured that CircutexVR remains at the cutting edge of educational innovation, offering valuable skills and knowledge to the next generation of students in the textile industry.

Figure 35. Students testing CircutexVR

5 Conclusion

5.1 Recap of Research Findings

The exploration of virtual reality in education, particularly through the CircutexVR project, has illuminated its potential to significantly transform how students learn about textile sciences. This virtual reality application enhances the educational experience by providing an immersive, interactive environment that enables students to engage with complex processes and theories in a hands-on manner. The traditional barriers of classroom learning, such as the limitations of physical resources and the abstract nature of certain topics, are overcome by the use of this advanced technology.

The immersive nature of VR allows for the visualization of textile processes that are difficult to convey through textbooks or traditional lectures. For instance, students are able to see and interact with 3D models of textile fibres and witness the impact of various tests and treatments on these materials in real-time. This not only aids in understanding complex concepts but also retains student interest and engagement, as they can directly observe the outcomes of their actions within a controlled, virtual environment.

A notable finding from the implementation of CircutexVR is the significant increase in student engagement. The interactive and engaging nature of VR stimulates curiosity and encourages students to explore learning materials more deeply. This engagement is critical in educational settings as it promotes active learning and deepens students' understanding of the subject matter.

Moreover, the feedback collected from users has been overwhelmingly positive, highlighting the usability and effectiveness of the VR platform in providing a comprehensive educational experience. This feedback has been instrumental in refining CircutexVR, addressing both minor and substantial user interface improvements, enhancing the educational content, and ensuring the platform remains aligned with educational standards and technological advancements.

Furthermore, the results from quantitative measures such as test scores and retention rates have shown a marked improvement among students who have utilized the VR platform. This suggests that VR not only enhances the learning experience but also contributes to better educational outcomes. Qualitatively, students have reported greater satisfaction with their learning experiences and a stronger confidence in their ability to understand and apply what they have learned.

These findings collectively demonstrate the powerful role that VR can play in modern education. By providing an engaging, interactive, and practical experience, VR has the potential to revolutionize traditional learning methodologies and offer students a dynamic and immersive way to gain education and training in complex fields such as textile sciences. The success of the CircutexVR project serves as a promising model for future applications of VR in education, highlighting its potential to enhance learning outcomes across various disciplines.

5.2 Contributions to Educational Technology

The integration of virtual reality (VR) into educational settings, as demonstrated by the CircutexVR project, represents a significant advancement in the field of educational technology. The project has not only showcased the potential of VR to enhance the learning experience but also set a benchmark for the future development of educational tools. VR technology's ability to simulate complex environments and processes offers a dynamic new way for students to engage with educational content that was previously constrained by the physical limitations of the classroom or the static nature of textbook learning.

CircutexVR's contributions to educational technology are profound, primarily in its ability to bridge the gap between theoretical knowledge and practical application. In traditional educational models, especially in fields like textile sciences, there is often a disconnect between what students learn in textbooks and what they are able to practice. VR technology effectively addresses this challenge by providing a virtual platform where students can interact with 3D models, perform experiments, and observe the outcomes of various processes in real-time. This hands-on approach not only solidifies theoretical knowledge but also enhances students' practical skills, preparing them for real-world applications.

Furthermore, CircutexVR has contributed to educational technology by offering customizable learning experiences that can adapt to different learning styles and paces. The flexibility of VR platforms allows educators to tailor content to meet the specific needs of their students, whether it involves adjusting the complexity of the simulations or providing additional resources within the virtual environment. This level of customization ensures that all students, regardless of their prior knowledge or learning speed, can benefit from the technology and achieve their educational goals.

Another significant contribution of CircutexVR to educational technology is its capacity to provide immediate feedback. In a VR environment, students can receive real-time responses to their actions, which is crucial for effective learning. This immediate feedback helps students quickly understand the consequences of their actions and correct their mistakes, leading to a more efficient learning process. It also fosters a supportive learning environment where students can experiment and learn without the fear of real-world consequences, encouraging exploration and innovation. But this fear is not that positive to learn without it.

While the CircutexVR project brings numerous advantages to educational settings by using virtual reality, it also presents certain challenges that are important to consider. One significant challenge is related to the lack of real-world consequences within the VR environment. In the safety of a virtual setting, students can perform actions without the fear of real-life repercussions, which, while encouraging exploration and learning, might also foster a false sense of security.

In practical terms, this means students might become accustomed to handling virtual materials and equipment without the natural caution required in a real laboratory setting. For example, in a VR setting, a student might interact with hazardous materials like acids without proper safety measures, because the virtual environment doesn’t penalize them for the lack of safety gear or unsafe practices. This can lead to the development of bad habits that, if carried over to real-world labs, could result in unsafe practices and accidents.

Moreover, the immersive nature of VR can sometimes make it difficult for students to differentiate between what can be safely attempted in a virtual lab versus a real one. This is particularly concerning in disciplines like textile sciences and chemical engineering, where incorrect handling of materials can have dangerous consequences. While VR environments strive to simulate reality as closely as possible, they currently lack the ability to fully replicate the tactile feedback and physical resistance that real objects provide. This discrepancy can affect the development of fine motor skills and the intuitive understanding of material properties, both of which are crucial in many scientific and engineering tasks.

To address these challenges, educational programs utilizing VR technologies like CircutexVR need to integrate specific training modules that emphasize the differences between virtual and real-world environments. Educators must ensure that students understand the limitations of VR and the importance of safety protocols in actual laboratory settings. Additionally, integrating hybrid learning models that combine VR with hands-on laboratory experiences could help bridge the gap between virtual learning and real-world application. This approach would allow students to apply the knowledge and skills learned in VR under the direct supervision of instructors in a controlled, yet real, environment, reinforcing safe practices and mitigating the risks associated with false security developed in virtual scenarios.

5.3 The Future of Virtual Reality in Education

The future of virtual reality (VR) in education looks incredibly promising as it continues to evolve and integrate deeper into educational systems around the world. As VR technology becomes more advanced, accessible, and cost-effective, its potential applications within educational settings are expanding dramatically. The immersive nature of VR has already demonstrated significant benefits in fields such as textile sciences, medical training, and engineering, allowing students to experience and interact with complex subjects in a dynamic and engaging way.

Looking ahead, VR is set to transform traditional learning environments by providing students with experiences that are not just about immersion but also about interaction with educational content that extends beyond the physical classroom. This shift could particularly benefit disciplines that involve spatial learning and motor skills, where the three-dimensional aspect of VR can offer a more intuitive understanding of abstract concepts.

Moreover, as VR technologies advance, the integration of artificial intelligence (AI) could lead to adaptive learning environments that respond to the needs of individual students. These smart learning environments could customize educational experiences, adjusting the complexity of tasks in real-time based on the student’s performance and engagement level. This would not only enhance learning outcomes but also make education more inclusive by catering to diverse learning styles and paces.

Another exciting prospect for VR in education is its potential to facilitate global classrooms without geographical barriers. Students from around the world could join a virtual classroom, participate in real-time, and collaborate on projects as if they were in the same room. This could foster international cooperation and understanding among students of different cultural backgrounds, preparing them for a globalized workforce.

However, the expansion of VR in education also presents challenges that must be addressed to fully harness its potential. Issues such as the digital divide could widen if access to VR technology is limited to students in higher socioeconomic brackets or developed countries. Ensuring equitable access to this technology will be crucial to prevent exacerbating existing educational inequalities.

Furthermore, the increased use of VR raises concerns about screen time and the physical implications of prolonged use of headsets. Educational institutions will need to find a balance to incorporate VR healthily and productively into curriculums without causing fatigue or other negative health impacts.

As VR continues to develop, it will be important for educators, technologists, and policymakers to work together to navigate these challenges. They will need to establish guidelines for the effective and ethical use of VR in education, ensuring that it supports educational goals while also considering the wellbeing of students.

5.4 Closing Remarks and Future Research Prospects

In closing, this thesis has thoroughly examined the potential of virtual reality (VR) technologies to transform educational experiences, focusing significantly on the CircutexVR simulation. The insights gained point to VR's robust capabilities to enrich learning, although recognizing its current limitations is essential.

Looking ahead, further research is imperative to leverage VR's full educational potential. Studies could delve into the integration of VR with conventional learning frameworks, enhancing the user interface for ease and intuitiveness, and developing advanced assessment tools that provide immediate feedback within VR environments. Moreover, longitudinal research is needed to evaluate the sustained impact of VR on educational outcomes and to assess how VR-acquired skills translate into practical applications.

Additionally, ensuring that VR is accessible to all learners, including those with disabilities, is vital. This inclusivity could be fostered through adaptive technologies that accommodate a broader audience. Also, considering the ethical implications related to data privacy and the psychological impact of long VR sessions will be crucial as VR usage expands.

By tackling these challenges, future research can refine VR's educational applications, making it a more adaptable and inclusive tool that meets diverse learning needs. As VR technology continues to evolve, its integration into educational settings promises to revolutionize how students engage with and absorb complex subjects, making learning an increasingly immersive and interactive experience.

The ongoing exploration into virtual reality's role in education reflects a burgeoning interest in making learning more dynamic and experiential. As VR technologies evolve, they promise a future where education transcends traditional boundaries, offering immersive experiences that were previously inconceivable. However, this promising future also brings with it a set of challenges that must be meticulously addressed to ensure the successful integration of VR into educational systems.

One of the pivotal challenges is creating VR content that is pedagogically sound and aligns with educational curricula. As educators begin to integrate VR into their teaching practices, there is a pressing need for content that not only engages students but also enhances their understanding of complex concepts. This involves collaboration between content developers, educators, and subject matter experts to produce VR experiences that are both accurate and educational.

Furthermore, the technological aspect of VR, particularly the hardware, presents another significant challenge. Current VR setups often require expensive equipment and considerable space, which can be prohibitive for many educational institutions. Research into more cost-effective, compact, and user-friendly VR systems is crucial to broaden the technology's accessibility. This could potentially involve the development of VR applications that are compatible with smartphones or lower-cost VR headsets, making educational VR more accessible to schools with limited budgets.

The assessment of learning outcomes in VR is another area ripe for research. Traditional testing methods may not effectively measure the skills and knowledge acquired in a VR environment. As such, new assessment frameworks need to be developed that can accurately evaluate both cognitive and practical skills within VR settings. These assessments should be designed to gauge a student's ability to apply learned skills in real-world situations, a critical measure of VR's efficacy in education.

Finally, as VR becomes more prevalent in educational settings, it is crucial to continuously monitor and study its impacts on students' cognitive and emotional well-being. Prolonged exposure to virtual environments may have unforeseen effects, necessitating ongoing research to ensure that VR is a beneficial educational tool rather than a detriment.

Overall, while virtual reality holds tremendous potential to revolutionize educational methodologies, its successful implementation will depend on careful consideration of content quality, technological accessibility, assessment methods, and long-term impacts on learners. Addressing these factors effectively will be key to unlocking the full potential of VR in education and ensuring it contributes positively to the educational landscape.

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My appreciation also extends to my peers and colleagues whose contributions, feedback, and encouragement have enriched this research. Their perspectives and expertise have added depth and rigor to my work, pushing me to strive for excellence.

Thank you all for your invaluable contributions and for believing in the potential of virtual reality to transform educational landscapes. Your support and guidance have been crucial to the success of this project and will continue to inspire my future endeavours in the field of educational technology.

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