Designing a Simulation showcasing the Pharmacological Effects of Beta-2-Agonists in Asthma Treatment;

Virtual Reality as a supplement to traditional teaching methods

Kristian Avlesbug, Joakim Skålevik Hansen

Master's thesis in Software Engineering at

Department of Computer science, Electrical engineering and Mathematical sciences,
Western Norway University of Applied Sciences

Department of Informatics,
University of Bergen

June 2023

Abstract

As educational technology evolves, there is a growing interest in applying VR in teaching complex scientific concepts that benefit from a visual and immersive learning environment. Motivated by the promising results of VR in medical education across multiple disciplines, we aimed to investigate the applicability and effectiveness of this technology in pharmacology education. This discipline, which involves understanding how drugs work within the human body, is often considered complex and challenging for students. However, it is a critical component of medical education and is essential in treating and preventing various diseases.

The study was driven by two research inquiries. The primary inquiry aimed to explore the potential design possibilities of a virtual reality (VR) simulation for visualizing the pharmacological effects of beta-2-agonists in asthma treatment. The secondary question focused on evaluating the perspectives of students and educators regarding the efficacy of the VR application in learning pharmacology concepts compared to conventional teaching approaches.

The application underwent two rounds of evaluation sessions with both students and teachers. Participants responded positively to the immersive learning experience, particularly appreciating the detailed visualizations and interactivity offered by the VR application. Their feedback highlighted the potential of VR to create a more intuitive understanding of complex pharmacological processes. Despite the evaluation phase featuring a limited number of participants, the received feedback suggested a promising potential for VR as an additional tool. The study, therefore, serves as a proof of concept, showcasing the possibilities of VR in enhancing pharmacology education and paving the way for future research and development in this area.

Acknowledgements

We would like to thank our collaborators at Helse Vest, Jon Andsnes Berg, and Trond Trætteberg Serkland, for their invaluable contributions to this project. Their input and expertise in the domain have helped shape the direction and success of this project. We are grateful for their willingness to collaborate with us and share their insights and experience.

We would also like to extend our appreciation to our supervisors at the Western Norway University of Applied Sciences (HVL), Harald Soleim and Atle Birger Geitung. Their guidance, support, and constructive criticism have been instrumental in our research process.

A special thanks to el Houcine Messaoudi for his willingness to provide insightful input and offer testers for the application. Furthermore, our gratitude is extended to all the individuals who actively engaged in the user evaluation sessions.

Acronyms

BPC Bézier Path Creator. 51, 53, 55, 57, 63, 85, 86

DOF Degrees of Freedom. 14
DSR Design Science Research. 18, 20–22, 24, 25, 83, 87

FOV field of view. 13, 14

HMD head-mounted display. 13, 14, Glossary: head-mounted display
HUH Haukeland University Hospital. 5, 51, 76
HVL Western Norway University of Applied Sciences. 1, 79

SUS System Usability Scale. 26–28, 77, 78, 80, 82–87, 93, 94

UI User Interface. 26, 45, 48, 57, 60, 72, 73, 76, 77, 80, 84, 86, 87, 92
UiB University of Bergen. 2, 76

VR virtual reality. 1–8, 12–16, 18–20, 23–26, 28, 29, 44, 45, 55, 56, 58, 62, 69, 70, 74–84, 86–94, Glossary: virtual reality

Glossary

anatomy teaching The educational process that delves into the structure and function of body parts in living organisms. In the context of VR, it allows for an immersive exploration of anatomical 3D structures and physiological processes. 3, 8

asthma management The ongoing process of medical care and lifestyle adjustments to control asthma symptoms and prevent asthma attacks. 11, 91, 92

beta-2-agonist A class of drugs that relax and widen the muscles of the airways, resulting in easier breathing. They are often used to treat conditions that lead to narrowed airways, such as asthma. In the context of short-acting beta-2-agonists, these medications provide quick relief from acute symptoms. 3, 5, 10, 55, 62, 65, 81, 91–93

component In 3ds Max, a component refers to the fundamental parts of a 3D model, including vertices (corners), edges (lines), polygons (faces), and more. These components can be selected and manipulated individually or in groups to model and modify 3D objects. 35, 36

GameObject The base class for all entities in Unity scenes. Game objects can have components attached to them to define their behavior. 48, 49, 51, 55, 56, 73

haptic feedback Refers to the tactile sensation or physical vibrations generated by a device or interface to enhance user experience and provide sensory cues. 14

head-mounted display In the context of virtual reality, a head-mounted display (HMD) is a wearable device that provides immersive virtual experiences. It achieves this by projecting images onto screens close to the user's eyes, creating the illusion of being in a different environment or reality. 12, 13

morph target A morph target is a deformed version of a shape that can be used to create a transition between two shapes. In the context of 3ds Max, this technique is often used in animations to smoothly transition between different states of a model. 41

refresh rate Refresh rate, in the context of displays, refers to the number of times per second that an image on a screen is updated or refreshed, measured in hertz (Hz), which affects the smoothness and responsiveness of visual content. 14

scene A container for a set of assets, game objects, and environments. Each scene represents a different level or part of your game. 17, 29, 40, 79

unity A cross-platform game engine developed by Unity Technologies, used to develop video games for PC, consoles, mobile devices, and websites. 16, 17, 36, 40, 44, 45, 48, 73, 84

Unity Asset Store A marketplace where creators can find, buy, and sell assets to use in their own Unity projects. 85

virtual reality Computer-generated simulation of a three-dimensional environment, allowing users to interact within a virtual world. 1

Contents

Chapter 1

Introduction

1.1 Motivation and Problem Description

Virtual Reality (VR) is increasingly being used to aid education across multiple domains [1]. Numerous studies have explored the potential benefits of incorporating VR technology into education. These studies have examined VR's impact on learning outcomes, student engagement, and more. Results from existing studies suggest that VR can be a valuable tool for improving education across a wide range of subjects and domains. Coupled with recent technological advancements making VR more accessible, the future of VR in healthcare education is exciting and full of possibilities. Pellas et al. [2] stated, "The abundance of computing resources and devices that support new dimensions of VR technology alongside the realistic simulated representational fidelity of visual objects and elements generated by computer graphics create unprecedented opportunities in teaching and learning."

Healthcare is considered one of the biggest adopters of VR training [3]. It has already been used in the mental health domain [4] for areas like exposure and distraction therapy [5][3]. Additionally, the adoption seems to be high for educational programs teaching procedural skills and clinical training. The midwifery program at the Western Norway University of Applied Sciences (HVL) has already embraced and integrated the technology into its curriculum. The ability to repeatedly simulate and practice clinical scenarios without putting patients at risk, coupled with the fact that active engagement has become widely acknowledged as an essential part of the learning process [6], has been a selling point for adopters of VR in healthcare education.

The integration of VR technology in pharmacology education, however, remains an area that has not been extensively explored. Pharmacology is the branch of medicine concerned with the uses, effects, and mechanisms of action of prescription drugs. It encompasses the study of how medications impact the body and their metabolic processes [7].

Pharmacology education involves learning about the effects of medicines on the human body and the processes by which the body metabolises these substances.

Students are introduced to the intricate mechanisms of drug metabolism within the human body, including the distribution of medications from their entry points to their intended targets, as well as the interactions between these medications and various organs. Notably, a single medication may be administered via different routes, such as oral ingestion or intravenous injection, resulting in distinct trajectories within the body and ultimately leading to variations in therapeutic effects [8].

This limited exploration of VR technology in Pharmacology education may be attributed to certain studies indicating that VR exhibits greater efficacy in teaching procedural skills rather than enhancing general knowledge among students [2]. However, Kyaw et al. [9] have found evidence suggesting that VR improves postintervention knowledge and skills outcomes of health professionals when compared with traditional education or other types of digital education such as online or offline digital education.

Regardless, our collaborators, Jon Andsnes Berg and Trond Trætteberg Serkland, who teach pharmacology at the University of Bergen (UiB), are increasingly seeing a need for developing different teaching methods in this domain. Their personal experiences seem to align with the findings of Supper et al.[10] and Ashour et al. [11], that there is a growing expectation from learners regarding the use of technology in education. A study conducted by Bati et al., published in 2013, explored the reasons behind students' non-attendance of lectures within medical educational programs at Ege University [12]. Among the 663 participants involved in the study, 45.8 percent of respondents expressed agreement or strong agreement with the statement "The lectures are boring" as a contributing factor for their lecture absences. VR has the potential to address this issue by offering an engaging and immersive learning experience that could potentially mitigate the perceived boredom associated with traditional lectures.

In addition to students' expectations changing, traditional teaching methods do not always provide the best platform for learning, and the methods used during medical education can have a significant impact on learning among medical students [13]. These traditional methods, often characterized by their focus on memorisation of facts and concepts, are conveyed through lectures, textbooks or videos [14]. Supper et al. [15] states that bridging the gap between teachers and students is a key challenge of medical didactics.

Berg and Serkland have identified VR as a tool that could mitigate some of the existing barriers and challenges. Recognising the educational benefits observed in various domains, they proposed a project aimed to develop a VR application that could be used as a supplement to traditional teaching methods in pharmacology education. Furthermore, the notion of utilising VR to explore pharmacological concepts has also been suggested by Coyne et al. [6], emphasising the potential of VR as a platform for providing immersive learning experiences in the field of pharmacology.

Virtual technologies hold the potential to foster increased commitment and motivation among students [17]. Notably, VR has demonstrated the ability to enhance learning outcomes in certain instances [18]. A study from 2018 concluded that integrating VR into neuroanatomy training may improve knowledge retention and increase study motivation [19]. Given the applied nature of the

Figure 1.1: VR in medication
[16]

pharmacology discipline, Berg and Serkland have theorized that integrating VR elements into the classroom setting could prove beneficial for pharmacology students. This proposition finds support in findings from other domains, such as anatomy teaching and midwifery education, where the incorporation of VR has yielded positive educational outcomes [20][21].

Allowing students to follow the journey a medical substance takes through the body could give them a greater understanding of its mode of operation. An interactive VR experience could give students the opportunity to explore what happens inside the body when a substance is absorbed in a new way. This would provide opportunities for active learning, which research has found can be more effective than passive learning [22] and at the same time cater to students growing expectations for the use of technology in higher education [23]. Being able to go in and out of organs and see how medications work from within could give the students the opportunity and freedom to observe specific pharmacological concepts at their own pace and accord.

The superior aim of this project is to investigate the perceptions and motivations of pharmacology students and educators to adopt VR elements that have shown positive signs in other fields. While it is possible that VR may have an impact on learning outcomes, it would not be possible to do any meaningful research into this due to the limited time frame of the project. Instead, this thesis will explore the technological possibilities and limitations of VR used in pharmacology education through the development of a ”proof of concept” VR application. It will further utilise this application to evaluate the perception and motivation of students and educators.

Our research questions will be addressed by utilising the design science principles and methods more extensively described in Chapter 3. The software engineering part of the project will be to develop a proof of concept VR application, an *artifact*, that shows how VR could be used to visualise the effects different medicinal drugs have on the human body. Specifically it will showcase the effects Beta-2-agonist have on the lungs in the treatment of acute asthma attacks. Users should have the ability to follow a specific medicine from the point of ingestion to its target destination in the body, where it takes effect. With a user-friendly interface, the application should be easy to use and understand, with clear explanations and graphics to help the students understand the processes that take place in the body. The *artifact* will then be used to gather feedback through user testing and evaluation.

1.2 Research Questions

The field of pharmacology requires a practical understanding of how medications interact with the human body. Therefore, we hypothesised that an interactive VR experience would give pharmacology students the opportunity to explore and better understand the processes that take place in the body, potentially leading to increased engagement and motivation. To address these speculations, we formulated two research questions to explore VR technology being introduced to Pharmacology education.

- **How can we design a Virtual Reality simulation that enables users to observe the pharmacological effects of beta-2-agonists in the treatment of asthma?**
- **How do students perceive the effectiveness of VR applications in helping them learn pharmacology concepts compared to traditional teaching methods such as lectures, textbooks, or videos?**

1.3 Scope & Limitations

Developing a VR solution can be a time-consuming process, so it was important to set realistic goals and priorities for the project. From the perspective of our collaborators, Berg and Serkland, the ultimate aim is to develop a comprehensive VR application that provides an in-depth exploration of various medications, utilising the full potential of available technology. In addition, this application would be integrated into the educational program, providing coverage across multiple curriculum areas. However, due to the time frame of this project, it would be challenging to cover multiple medicines in detail.

A VR solution could provide a broad overview of multiple medications. Instead of covering every detail of multiple medications, it could provide a broad overview of various types of drugs. However, after considering the options and the constraints of the time frame, the choice was made to focus the VR solution on a single class of medication.

Keeping the future use of such an application in mind, it was decided that this approach would give the tester a better idea of the usefulness of a finished medical catalogue in VR. Considering the target audiences also contributed to the decision to go deeper into one type of medication. As a result of their existing knowledge of medications and their overall understanding of the field of medicine, they may have higher expectations regarding realism and pharmacological accuracy. These expectations would be easier to meet when focusing the VR application on one specific type of medication.

When contemplating the selection of an appropriate medication, the available options appeared virtually boundless, encompassing a plethora of pharmaceutical interventions. This complexity is further magnified by the diverse pharmacological mechanisms these medications elicit within the human body. In the USA alone, over 20,000 prescription drug products are approved for marketing [24].

Discussions with domain experts at Haukeland University Hospital (HUH) led to the decision to focus the VR application on asthma medication. Asthma was chosen, in part, due to its widespread recognition as a well-established condition, fostering a level of familiarity and pre-existing knowledge among a substantial portion of the general population. In particular, we chose to showcase *short-acting beta-2-agonists*, which is a type of medication used to provide rapid relief of asthma symptoms. Being quick-relief medications, simulating their effects seemed more straightforward than a medication where it would take days to see the full extent of its impact. This characteristic makes Beta-2-agonist medications a fitting choice for demonstrating the potential of VR in pharmacology education.

The application developed for this thesis aims to showcase these medications employed in the treatment of bronchial asthma, specifically focusing on inhalers and drugs that facilitate the dilation of airways. These medications were chosen as they exemplify the challenges often encountered in conveying their mechanisms and therapeutic effects through conventional teaching methods.

Evaluating the impact of a VR solution on students' learning outcomes would be valuable, as it could provide further insight into the effectiveness of using VR technology in education. However, conducting such an analysis is beyond the scope of this study, as the substantial amount of work, time, and resources required to measure this effect cannot be accommodated within the current project.

1.4 Related Work

Several studies have been performed on the use of VR as an educational tool in various domains. Perhaps the most closely related ones are the studies looking at the use of VR to teach human anatomy. During the project period, we have not come across any studies that focus specifically on VR in pharmacology.

Prior research has yielded varied findings concerning the outcomes of students utilising VR compared to those following conventional educational programs. These investigations have delved into a range of aspects, including learning outcomes, knowledge retention, and classroom engagement, among other variables.

1.4.1 VR in Education

VR technology has been widely studied for its potential impact on education. The argument for the use of VR in education revolves around its capacity for simulation-based education. This allows students to practice new skills in a safe and controlled environment, facilitating correction, repetition, and nondangerous failure. Simultaneously, VR offers access to interaction with expensive or far-away environments [25].

A literature review [2] of studies conducted in the last decade on the use of immersive virtual reality in Primary and Secondary school and higher education settings found that several studies have reported better learning performance and outcomes for students who utilised VR applications. These findings include positive results in terms of deep learning of complex knowledge and the cultivation of cognitive thinking skills such as creativity, problem-solving, critical thinking, and metacognition. However, there is also a body of research that has found mixed or negative results [2].

Some studies could not report improvement in learning outcomes but could report positive users' attitudes and perceptions regarding VR usage, such as engagement, motivation, presence, increased self-efficacy, and reduced learning anxiety. One aspect highlighted by Makransky et al. [26] is that instructional media can increase the fun of a simulation, such as the sense of presence, but it does not necessarily make someone learn better. Other studies reported contradictory results, such as findings that VR harmed students' engagement or that it may overload and distract students' attention to understanding learning material, possibly due to the novelty of VR technology uses.

In higher education settings, users seemed to have positive attitudes and perceptions of using VR applications, even if technology limitations and potential complexity are factors that need to be addressed in the future [2].

While schools and educators embrace digitisation and new technologies [27], the usefulness of VR in education seems to depend on its implementation. Factors like equipment and software quality can impact the experience of users. However, when executed effectively, the use of VR in education can provide benefits to student engagement, motivation, and even learning outcomes [2].

1.4.2 VR in Healthcare

In addition to education, VR technology has been gaining traction in the healthcare industry as a means of providing patients with new and innovative treatment options as well as giving patients a better understanding of the treatment they are receiving. The use of VR in healthcare has been shown to be effective in a variety of areas, including pain management, physical therapy, and mental health treatment [6].

One promising area of VR in healthcare is the management of acute and chronic pain [28]. Studies have shown that VR can be used to distract patients from their pain and provide them with a sense of control over their pain. VR has also been used to help patients with chronic pain to better cope with their condition and improve their quality of life.

Another area where VR is being used in healthcare is in physical therapy. VR can be used to provide patients with immersive, interactive rehabilitation exercises that can help them to improve their strength, balance, and coordination [29] [30]. VR has also been used to help patients with conditions such as stroke or spinal cord injury [31] [32] [33].

Mental health is another area where VR is being used in healthcare. VR can be used to provide patients with virtual exposure therapy for conditions such as post-traumatic stress disorder (PTSD) or phobias [3] [6]. VR has also been used to provide patients with virtual reality-based cognitive behavioural therapy (VR-CBT) to help them cope with anxiety and depression [34] [35].

Despite the potential benefits of VR in healthcare, the technology has some limitations. One of the biggest limitations is the cost of VR equipment, which can be expensive for many patients and healthcare providers [36]. Currently, VR research in healthcare is still in its early stages. More research is needed to fully understand the potential benefits and limitations of VR technology and to develop best practices for its use in healthcare. Future directions for VR research in healthcare include developing more affordable VR equipment and developing VR-based interventions for a wider range of conditions.

In conclusion, the use of VR in healthcare has the potential to provide patients with new and innovative treatment options for a variety of conditions. While there are limitations to the technology, the potential benefits of VR in healthcare make it an area worth exploring further. As research in this field continues to evolve, we can expect to see even more ways in which VR can be used to improve patients' lives.

1.4.3 VR in Medical Education

A promising area of VR in health domain is medical education. VR technology has been used to educate medical students in various areas, including anatomy, surgery, and patient care [37].

An inherent advantage associated with the integration of VR in medical education lies in its capacity to afford students the opportunity to engage in repetitive simulations within an immersive environment. VR offers students a unique opportunity to visualise intricate concepts and procedures, bypassing the limitations of conventional instructional methods such as textbooks or lectures. In addition, VR provides a controlled and secure environment wherein students can safely practice and refine their procedural skills prior to their application to actual patients [38]. An example that capitalises on this advantage of VR is the work conducted by Rossler et al. [39]. The study specifically focused on devising medication administration error scenarios tailored for nursing students.

Along with anatomy and surgery, VR has also been used to train medical students in patient care [40]. VR simulations can provide students with the opportunity to practice communication and diagnostic skills in a realistic yet controlled environment. Moreover, VR technology is being used to train medical students in emergency medicine with simulations of critical care scenarios[41]. It allows students to experience different situations and improve their critical thinking and decision-making skills.

A study from 2017 [42] aimed to evaluate the effectiveness of VR and augmented reality (AR) compared to tablet-based applications in enhancing students' learning outcomes in structural anatomy. The study found that there was no significant variation in the anatomical test scores among the three groups. However, it was determined that while the anatomical test scores were similar across the three groups, both VR and AR offer additional intrinsic benefits such as improved student engagement, interactivity, and enjoyment. This finding highlights the potential of VR and AR as useful tools for future learning within health sciences and medical curricula.

Within anatomy education, VR technology has been increasingly utilized as a tool to improve student understanding and engagement. A recent meta-analysis from 2020 [20] aimed to investigate the educational effectiveness of VR in comparison to conventional or 2D digital methods in anatomy education. The study found that overall, VR education had a positive effect on test scores compared to other teaching methods. Additionally, that most students have a greater interest in learning via VR methods.

The findings of this study can also have potential benefits in the field of pharmacology teaching. As with anatomy, pharmacology students may experience difficulty in acquiring an adequate understanding of three-dimensional concepts from traditional teaching methods such as lectures and textbook illustrations. By allowing students to fully immerse themselves in a virtual environment, VR can assist them in gaining a deeper understanding of the complex interactions and processes of drugs within the human body.

Additionally, VR technology can also increase engagement and motivation. As the study suggests, VR education can lead to higher satisfaction levels among students, which can be beneficial in a field such as pharmacology, where material may be perceived as dry or theoretical. By offering an interactive and immersive learning experience, VR can make the learning process more engaging and motivating.

Despite the potential benefits of VR in medical education, it should be noted that more research is needed to fully understand its effectiveness. Additionally, the cost of VR equipment can be a barrier to the widespread adoption of VR technology in medical education.

In summary, VR technology has the potential to revolutionise medical education by providing students with an immersive and interactive learning experience. While more research is needed to fully understand the effectiveness of VR in medical education, earlier studies have shown promising results. As VR technology continues to evolve, we can expect to see even more ways in which it can be used to educate and train the next generation of healthcare professionals.

Chapter 2

Background

2.1 Pharmacology

Pharmacology is the science of medicinal drug actions on biological systems, one of the principal ways of treating disease [43]. It is the branch of medicine concerned with the uses, effects, and modes of action of prescription drugs [7]. Pharmacology includes both pharmacodynamics and pharmacokinetics. Pharmacodynamics is the study of a drug's molecular, biochemical, and physiologic effects or actions. All drugs produce their effects by interacting with biological structures or targets at the molecular level to induce a change in how the target molecule functions in regard to subsequent intermolecular interactions [44]. Pharmacokinetics is the study of how the body interacts with administered substances for the entire duration of exposure. The four main parameters generally examined by this field include absorption, distribution, metabolism, and excretion [45].

2.2 Asthma Bronchiale

Asthma bronchiale, also known as just asthma, is a chronic respiratory condition. The disease has no cure, but it can be managed so that people affected can live a normal, healthy life [46]. Asthma is characterized by inflammation and narrowing of the airways, illustrated in Figure 2.1, leading to difficulty breathing.

Symptoms of asthma may include:

- Shortness of breath, especially during physical activity or when exposed to triggers such as allergens or cold air
- Chest tightness or pain
- Difficulty speaking due to shortness of breath
- Fatigue or difficulty sleeping due to breathing difficulties

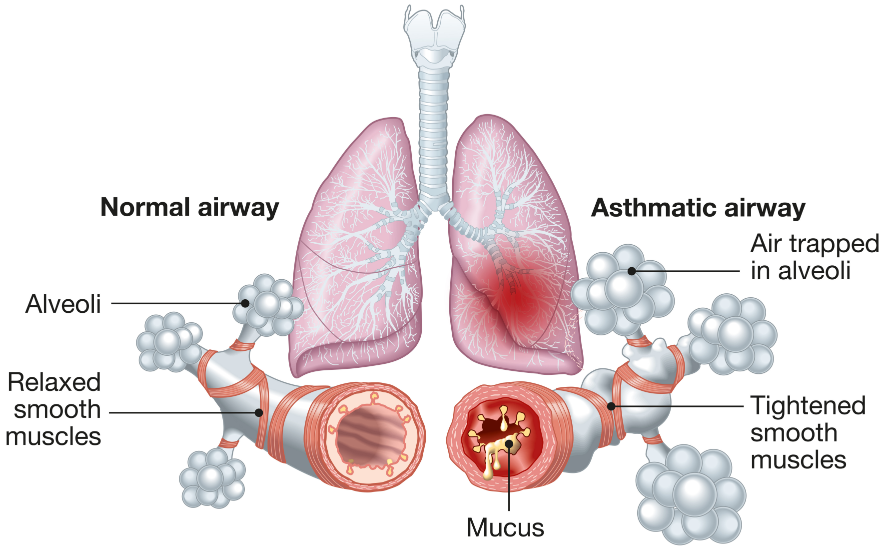


Figure 2.1: Asthma symptoms visualisation. Image from Adobe Stock [47]

Treatment of asthma typically involves a combination of medications and lifestyle changes to control symptoms and prevent attacks.

Medications used to treat asthma may include:

- Quick-relief medications, such as short-acting bronchodilators, which are used to relieve symptoms during an asthma attack
- Long-term control medications, such as inhaled corticosteroids, which are used to reduce inflammation and prevent future attacks

2.3 Beta-2-agonists

Beta-2-agonists represent a commonly prescribed class of medications utilised for the treatment of asthma bronchiale [48]. These medications function by stimulating the beta-2 receptors present in the airways, thereby inducing relaxation of the smooth muscle tissue surrounding the airways and facilitating an augmented airflow [49]. Often employed as a rapid-relief intervention for the management of asthma symptoms, including dyspnea, coughing, and wheezing, beta-2-agonists also serve as a preventive measure to reduce the frequency and severity of asthma attacks [48][50].

Multiple variants of beta-2-agonist medications are available, commonly administered through inhalation using metered-dose inhalers or nebulisers. Generally well-tolerated, these medications entail a low risk of severe adverse effects, although tremors, dizziness, or increased heart rate may manifest in certain individuals [51][52].

It is important to note that beta-2-agonists should not be used as a replacement for other asthma management strategies, such as the use of inhaled corticosteroids or allergen avoidance. Instead, these medications should be used in conjunction with other therapies as part of a comprehensive treatment plan [51].

2.4 Glucocorticoids

Glucocorticoids, also known as corticosteroids, are a type of medication also used to treat asthma bronchiale. These medications work by reducing inflammation in the airways, which can help improve symptoms such as shortness of breath, coughing, and wheezing.

Various forms of glucocorticoids, including inhaled and oral formulations, are available for asthma management. Inhaled glucocorticoids are considered the most efficient for long-term asthma control [53]. Administered through inhalers or nebulisers, shown in Figure 2.2 & Figure 2.3, inhaled glucocorticoids directly target the airways to exert their anti-inflammatory effects [54].

Figure 2.2: Inhaler. Image from Adobe Stock [55]

Figure 2.3: Nebuliser. Image from Adobe Stock [56]

Oral glucocorticoids may be used in the short term to control severe asthma symptoms or during an asthma exacerbation. However, these medications are not recommended for long-term use due to the risk of serious side effects [57], including osteoporosis, diabetes, and weight gain. In addition to reducing inflammation, glucocorticoids can also help to prevent asthma attacks and improve overall asthma control [51].

2.5 Virtual Reality

VR refers to the utilisation of computer technology to generate simulated environments that enable users to engage with artificial three-dimensional visual or sensory settings. VR applications create an immersive experience for individuals by presenting computer-generated environments that simulate reality. This is achieved through the integration of interactive devices, such as goggles, headsets, gloves, or body suits, which facilitate the transmission and reception of information [58].

Bailenson [59] explained that VR creates presence by executing the three technical elements of *tracking*, *rendering*, and *display* as flawlessly as possible. Tracking involves the precise measurement of body position, particularly head and hand position, as well as rotation. Rendering encompasses the transformation of mathematical data representing 3D models and environments into visual representations, a process that must be iterated for each frame to ensure accuracy and immersion. The display involves the presentation of these rendered images through specialised head-mounted displays (HMDs), typically equipped with individual screens for each eye and lenses that provide distinct perspectives, thereby creating the illusion of depth known as stereoscopy.

The future of VR has the potential to bring significant advances and changes to a wide range of industries, including education. In education, virtual technologies have the potential to make students feel more committed and motivated [17], and "VR" has been shown to improve learning outcomes in some cases [18]. As VR technology continues to evolve, it is expected to become more accessible, affordable, and user-friendly, making it easier for educators to integrate VR into their classrooms and curricula.

Figure 2.4: Meta Quest 2. Image from Adobe Stock [60]

2.5.1 A Short History of Virtual Reality

The term *Virtual Reality* was not coined until the late 1980s by Jaron Lanier [61]. However its history began many years earlier.

One of the earliest mentions of VR-like technology came from science fiction in Stanley G. Weinbaums's short story "Pygmalions's Spectacles". In 1935 the American writer presented a comprehensive description of a pair of goggles that enable "a movie that gives one sight and sound [...] taste, smell, and touch. [...] You are in the story, you speak to the shadows (characters) and they reply, and instead of being on a screen, the story is all about you, and you are in it [62]."

In 1962, Heilig Morton invented the Sensorama, an arcade game-looking device that integrates technology to allow an individual to view stereoscopic films. These films were enhanced with seat motion, vibration, stereo sound, wind, and aromas, which were triggered during the films, intending to fully immerse the individual in the film [63].

Six years later, in 1968, Ivan Sutherland and one of his students created what is considered the first VR head-mounted display system. In addition to displaying wireframe drawings, the system tracked the users' position and rotation and updated the content displayed accordingly. However, the technology was not very practical. Due to its weight, it had to be suspended from the ceiling. While it was very slow by modern standards, it was reportedly close enough to real-time to give the impression of standing inside a virtual environment.

Throughout the following decades, multiple different devices were invented, each contributing to the continuous development of Virtual Reality. Among them was the Visually Coupled Airborne Systems Simulator, demonstrated by Thomas Furness in 1982 [64]. Later, in 1988, VPL Research Inc. introduced the Eyephone HMD, and the Sega VR prototype debuted in 1993 [65]. However, VR did not take off, at least in terms of commercial use, until around 2014. On March. 25, Facebook announced that they had acquired Oculus VR for approximately $2 billion [66]. The acquisition, in addition to the release of the Oculus Rift, signaled the start of a major effort to get VR into the hands of the general public. Around the same time, Sony announced Project Morpheus, a VR system for their hugely successful gaming console, the PlayStation 4 [67]. Later that same year, Samsung announced the Samsung Gear VR [68].

Since then, the technology has gotten cheaper and better. Major companies backing the technology led to more and more developers creating games and applications for this "new" type of media. Advancements in areas like tracking and display technology have significantly improved the user experience. The degree of immersion users can achieve with VR headsets can be greatly enhanced by making them smaller and lighter.

2.5.2 VR: State of the art

Head-mounted displays (HMDs) are the primary hardware component of today's VR systems. To create a convincing illusion of being in a different environment, they provide a visual display that surrounds the user's field of view (FOV) [25]. The quality of HMDs varies based on technical specifications like resolution, refresh rate, and FOV, in addition to building quality and weight. The resolution of HMDs has improved significantly. The Oculus Quest 2, which was used in this project and is shown in Figure 2.4, has a resolution of 1920 x 1832 for each eye, a significant upgrade on the Oculus Rift resolution of 1080 × 1200 per eye [69]. The refresh rate, which affects the smoothness of the VR experience, has also increased on modern displays. Many HMDs now offer a refresh rate of 90 Hz or higher, reducing motion sickness for some users. The FOV of HMDs varies between models, with some providing a narrower view than others.

Tracking technology is a critical component of VR, as it enables users to move and interact with virtual environments [70]. Early consumer VR systems performed tracking through external sensors that detect the position and orientation of HMDs and controllers. However, newer VR systems use inside-out tracking, which relies on cameras or sensors built into the HMDs and controllers. This technology is more convenient for users, as they do not need to set up external sensors [71].

Degrees of Freedom (DOF) refers to the number of directions in which users can move in VR. Three DOF systems allow users to move their heads up/down, left/right, and forward/backward. Six DOF systems allow users to move their heads and body in all directions, making the VR experience more immersive. Many modern VR systems support six DOF [72].

Hand and controller tracking is a crucial feature of VR, as it enables users to interact with virtual environments in a natural and intuitive way [73] [74]. Advanced systems use sensors or cameras to track the position and orientation of hands and controllers accurately. This technology allows users to pick up virtual objects and manipulate them [75].

Commercially available VR systems today include the Oculus Quest 2, the Valve Index, and the HTC Vive Pro 2. The Oculus Quest 2 is a wireless, standalone system that offers six DOF tracking and a high-resolution display. The Valve Index and HTC Vive Pro 2 are tethered systems that offer advanced features such as finger tracking, haptic feedback, and high refresh rates [76].

More advanced VR systems include the Varjo XR-3, which offers high-resolution displays and advanced hand and eye-tracking [77], and the Pimax 8K X, which features a wide FOV and high resolution [78]. However, these systems are aimed at enterprise users and are not yet widely available to consumers.

2.6 Serious Games

One way of utilising VR in education is with the use of serious games. Serious games are digital games with an additional goal beyond entertainment [79]. This goal can be educational or related to various types of training [80]. By combining a serious objective with the entertainment games provide, serious games hope to keep players engaged while promoting learning, behaviour changes, and other serious objectives. Elements from game design, like competition and rewards, are used to keep players motivated and interested [81]. Furthermore, serious games can provide personalised learning experiences through the use of adaptive algorithms that adjust the difficulty level of the game based on the learner's performance. As a result, learners can work at their own pace and receive feedback tailored to their specific needs.

Serious games are used in various fields, including healthcare, education, military training, and emergency management [80]. For example, serious games have been used in healthcare to train medical professionals, simulate surgical procedures, and even help patients manage their own health conditions [82]. In education, serious games are used to teach a variety of subjects, from math and science [83] to history and social-emotional competence [84].

One of the challenges facing serious games is the cost and time required to develop high-quality products. Implementing serious games into education is not straightforward. However, Froland et al. [27] have found that their benefits seem to outweigh their drawbacks.

2.7 Game Engine

A *game engine* is a comprehensive software framework designed to facilitate the creation and development of video games. It provides developers with essential tools, libraries, and pre-built elements, allowing them to focus on designing, building, and refining their game's unique aspects without creating the underlying technology from scratch. Game engines handle various tasks, such as rendering graphics, simulating physics, and processing user input.

Game engines have a vital role in VR development. As VR technology aims to create immersive and interactive experiences, it requires a higher level of realism and responsiveness compared to traditional video games. Game engines that support VR development provide specialised tools and features specifically tailored to address the unique challenges of creating virtual environments. In addition, they need to support various input devices, such as VR headsets, motion controllers, and haptic feedback systems, to create a seamless and natural interaction for the users.

These engines are versatile and can be used for various purposes beyond just video game development. They provide a large selection of tools and functionalities that can be leveraged for different applications. Training and education can benefit significantly from this technology. Interactive learning experiences can be developed to teach complex concepts or skills and make education more engaging and effective. Game engines enable the creation of virtual classrooms, labs, and workshops, allowing students to practice and learn at their own pace, regardless of their physical location.

In the realm of simulations, game engines can be employed to create realistic scenarios for multiple industries. These simulations can help test and validate new designs, enhance safety protocols, or train professionals in various fields. One area where this technology has demonstrated significant potential is in the healthcare sector, which is closely linked to pharmacology. Utilising game engines for healthcare simulations offers several advantages, including cost-effectiveness, adaptability, and the ability to create complex, immersive environments that mimic real-life scenarios.

2.7.1 Choosing a Game Engine

In the context of developing a VR application, selecting the most fitting game engine is an important consideration that can significantly impact the application's outcome. Several game engines are available in the market, each with distinct advantages and disadvantages. In this project, we considered multiple options. Some of the leading game engines for VR development include Unity, Unreal Engine, and Godot Engine [85].

Unity is a versatile and widely-used game engine that supports various platforms, including VR. More than 50% of the world's video games are made with Unity [86]. Unity is an IDE, as well as a game engine, making it easier for developers to create complex applications. IDE stands for "integrated development environment", which describes an interface that gives you access to all the tools you need for development in one place [87]. Some of its features are illustrated in Figure 2.5. One of the primary reasons for choosing Unity was its extensive platform support, as it can accept projects across PCs, consoles, mobile devices, and VR/AR systems. Unity also has a large online community where users can share experiences and a wealth of resources, including tutorials, forums, and an asset store. The game engine itself provides tutorials, books, and even webinars [86] to help game developers get familiar with their tools and create the best product they can. These resources can help save time and effort when creating a VR application from scratch. However, Unity has its drawbacks. Licensing costs may be an issue for smaller teams or individual developers, as professional developers might need to pay for Unity Pro.

Figure 2.5: Game Engine illustration. Image from Adobe Stock [88]

As an alternative to Unity, the Unreal Engine [89] was brought up for consideration. Unreal Engine, developed by Epic Games, is another powerful game engine that is well-suited for game development. It has become popular for its high-quality graphics, advanced features and impressive performance. One of the key strengths of Unreal Engine is its ability to produce stunning, realistic visuals. It uses advanced rendering techniques, such as global illumination, physically-based rendering, and real-time ray tracing, which allows developers to create immersive and visually impressive games and applications. Unreal Engine also has a robust asset store, where developers can access a vast library of pre-built assets, tools, and plugins to streamline their development process.

Unity was ultimately selected as the preferred platform based on its advantages and perceived attributes of enhanced speed and cross-platform development support [90].

2.8 3D Software

Together with our collaboration partners, we agreed on some 3D models, which we went to purchase from TurboSquid [91]. Unfortunately, the format of these models was not compatible with Unity, so the solution was to use a program called 3ds MAX to convert them to a compatible format. 3ds Max is a professional 3D computer graphics program for creating 3D models, animations, and visual effects. It is widely used in the film, television, and gaming industries for creating high-quality 3D content. It offers a wide range of tools and features for modeling, texturing, animating, and rendering 3D objects and scenes, including support for particle simulations, character animation, and physics-based effects. It is a powerful and versatile tool that allows artists to easily create 3D graphics and animations.

Chapter 3

Research Methodology

To answer the research questions in this thesis, a variation of Design Science Research (DSR) was chosen as the methodology. This chapter provides an overview of the research methodology selection process and discusses the relevance and application of DSR in the context of this project. The rationale behind the choice of methodology will be illuminated, followed by a discussion on how DSR aligns with the research objectives and requirements of this thesis.

3.1 Choosing a Research Methodology

Selecting a research methodology for an interdisciplinary thesis requires careful consideration of some key requirements. The methodology should align with the overall research objectives and questions of the thesis. The methodology should also be appropriate for interdisciplinary research, as it involves the integration of knowledge from different fields, in this case, pharmacology, education, and computer science. It should allow for the exploration of both the educational and technological aspects of VR applied to pharmacology education. Additionally, the selected methodology should provide a rigorous approach to data collection, analysis, and interpretation.

The objective of this project was to develop a VR application that serves as a proof-of-concept for how VR can be used to showcase pharmacological effects of medications. This application would then be used to evaluating the acceptance and perception of VR technology in the context of pharmacology education. The specifications for the application were collaboratively formulated together with domain experts, and were subject to iterative refinement and modification throughout the entire development process.

Though it is not the primary emphasis of this thesis, the long-term goal of it being further refined and expanded into a comprehensive educational tool that can be used in classrooms and hospitals should also be considered. In the context of this thesis, the application would be used to assess the reception of VR technology in pharmacology through user evaluations.

The research methodology for this project should arguably lie somewhere in between the inductive and deductive approaches, with an emphasis on deductive. Whilst the research does not directly aim to prove or disprove a hypothesis, it does draw upon and build upon previous work from other domains. Some of the motivation behind the project originates from the positive results the use of VR has shown on education in other domains. At the same time, the inductive method is also employed, as the study allows for new themes and patterns to emerge from the data.

Similarly, the choice between qualitative and quantitative research design and data collection is not a straightforward one. The final quality of the designed artifact could benefit from qualitative methods like interviews, observations, or focus groups during the development process. Additionally, employing qualitative methods in the evaluation of the designed artifact could generate fascinating results. However, as this thesis aims to investigate the perceived usefulness of a novel technology introduced to a specific domain, quantitative research methods could be more appropriate for providing an objective evaluation. Additionally, these findings can then be generalized to a larger population.

One approach to answering RQ2 could be to employ a quasi-experimental research strategy. A VR application for pharmacology education could be introduced to a natural setting, and researchers could observe different causes and effects. With this approach field experiments would need to be carefully designed and conducted to either prove or disprove a hypothesis. To be able to confidently conclude that some factor A causes outcome B, the experiments must be repeatable, and factors must be removed and re-introduced several times. Once the sample size is deemed adequate, the data can be analysed, and generalizations can be made.

While an experimental research approach could help advance our understanding of the perception and acceptance of VR in the context of pharmacology education, it would require too many resources for this project. Experiments would have to be repeated multiple times on a large group of people to achieve statistically significant results, with the experiments themself requiring thorough planning to be conducted accurately enough to provide reliable data. Additionally, pre-test and post-test measurements are often necessary components of the experimentation process, resulting in the need for more time and resources.

A less resource-dependent alternative could be a Case Study. A pilot case or feasibility study could be undertaken to explore different aspects of using VR in the context of pharmacology education. The VR application would be introduced to a specific group of people in a single study. Through the use of qualitative methods, researches could go into depth on various facets of the research topic. The qualitative methods employed in case studies generally produce a more descriptive understanding of a specific phenomenon but come at the cost of lower levels of generalization. Whilst a case study would require fewer resources than an experiment, the inability to quickly remove and re-introduce variables can make them more time-consuming. Additionally, data collection methods typically used in case studies, like interviews and observations, are generally more labor-intensive [92].

Similarly, a more hands-on approach through action research could provide insightful results, but once again, the question of resources and time must be taken into consideration. Furthermore, in all the proposed approaches, the VR application would simply be a tool with which research is conducted. However, the development of the VR application itself is also an important aspect of this project. This is where a design and creation approach [92] can prove helpful. DSR provides a framework that facilitates both learnings during the development process and evaluations in a real-world context following the development conclusion. This approach makes the creation of the VR application itself a part of the research.

Considering that our research requirements called for the use of a mixed-methods approach and were compatible with the structured and iterative nature of the Design Science Paradigm, it was chosen as the starting point for our research method.

3.2 The Design Science Paradigm

DSR is a problem-solving paradigm that aims to increase knowledge through the creation of new artifacts. Brock et al. [93] put it simply, "DSR seeks to enhance technology and science knowledge bases via the creation of innovative artifacts that solve problems and improve the environment in which they are instantiated."

DSR results in both newly designed artifacts and new design knowledge. Although the artifacts created through DSR should be innovative or unique, in most cases, they build upon existing knowledge, revising, extending, and combining parts from preexisting solutions [93]. The existing knowledge base is expanded via design theories on why an artifact enhances its application context. Design knowledge refers to knowledge generated through DSR about how a solution to a real-world problem should or should not be constructed or arranged. It will include information about the problem, the designed solution, and the results gathered from evaluating the solution.

In addition to the Information Systems field, a multitude of other domains, including engineering, architecture, and economics, also adopt DSR as a prominent research paradigm. Regardless of the field in which it's applied, a set of needs are assessed and evaluated within that domain's context, and all these needs added up define the "research problem". Often research problems are unique. However, there are situations where an already studied set of needs can provide the starting point of a DSR project.

DSR projects conducted as information systems research typically produce what Gregor et al. [94] refer to as prescriptive knowledge. Winter et al. [32] described prescriptive knowledge as knowledge about technological innovations that directly affect individuals, organisations, or society while also enabling the development of future innovations.

The development of the DSR methodology has progressed to incorporate enhanced evaluation techniques that enable a more fine-grained and simultaneous evaluation of intermediate stages in the design process. Sonnenberg et al. [96] suggest that evaluations should be conducted throughout the whole process, including after the problem identification, meaning that researchers and share-

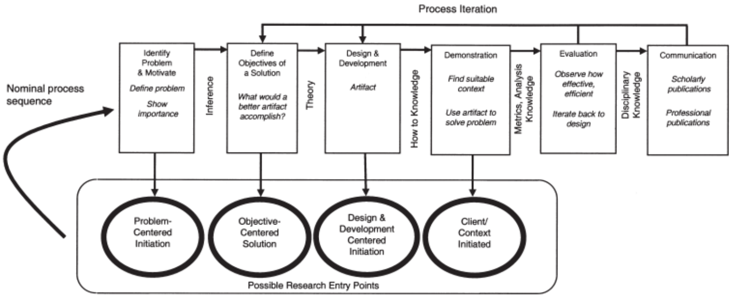


Figure 3.1: DSR methodology model from Peffers et al [95]

holders do not miss out on the opportunity to inform the design at an early stage. While early contributions to DSR focused on contributions to design entities, in 2007, Gregor and Jones [97] introduced the idea of DSR projects also producing design theory. Carstensen et al. [98] describe a design theory as providing instructions for 'how to do something'. Design theories are an established way of communicating a DSR knowledge contribution in IS research papers[99].

Several models for how one should perform DSR projects have been proposed, whit the most widely known model being proposed by Peffers et al. [95]. Their process includes six steps shown in Figure 3.1: problem identification and motivation, the definition of the objectives for a solution, design and development, demonstration, evaluation, and communication. In Hevner et al. [100], seven guidelines are established to assist researchers, reviewers, editors, and readers in understanding the requirements for effective DSR. The guidelines are summarised in Figure 3.2.

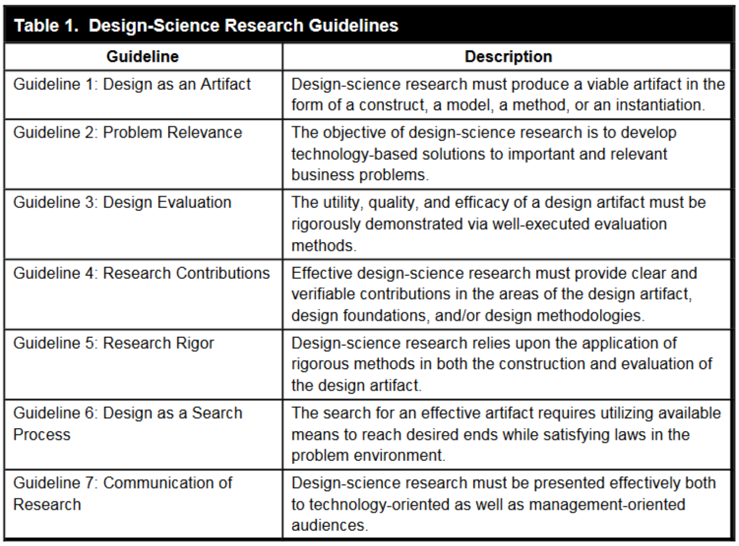


Table 1. Design-Science Research Guidelines

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Figure 3.2: Guidelines for DSR from Hevner et al [100]

In a commentary on Iivar's paper "A Paradigmatic Analysis of Information Systems As a Design Science" [101], Hevner [102] defined three cycles of DSR, the Relevance Cycle, the Design Cycle, and the Rigor Cycle, shown in Figure 3.3. Hevner suggests that all these three cycles should be present and clearly identifiable in a DSR project. To summarise, the relevance cycle focuses on identifying and defining the problem or opportunity that needs to be addressed. It involves understanding the context of the problem or opportunity in the real-world application domain and defining research requirements and acceptance criteria for evaluating the research results. This cycle sets the stage for the subsequent cycles and ensures that the research is relevant and aligned with real-world needs.

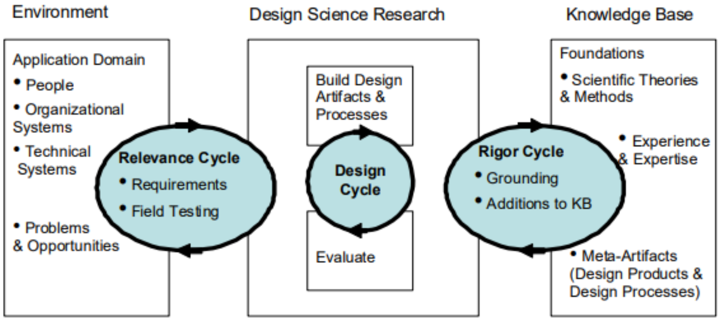


Figure 3.3: Hevner's three cycles of DSR [102]

The design cycle is where the artifact or solution's actual design and creation occur. It involves developing a solution or artifact based on established design principles and methods, and it may include iterative processes of designing, building, testing, and refining the artifact. The design cycle is the core of the DSR process, where the researcher creates a new solution or artifact to address the identified problem or opportunity.

Lastly, the rigor cycle focuses on evaluating the rigor or quality of the research conducted in the design cycle. It involves rigorously testing the artifact or solution using appropriate methods to assess its functionality, performance, usability, and other inherent qualities. The rigor cycle helps ensure that the research results are credible, reliable, and valid, and that the artifact or solution meets the established research requirements and acceptance criteria.

Design science involves a rigorous process of designing artifacts to solve observed problems, make research contributions, evaluate the designs, and communicate the results to appropriate audiences [103]. In the context of a DSR project, the creation of viable solution entities, efficient design processes, and robust design systems leads to the generation of new prescriptive knowledge. Whereas natural science tries to understand reality, design science attempts to create things that serve human purposes [104]. In simple terms, Hevner et al. [103] define design science as the process of creating and evaluating IT artifacts intended to solve identified organisational problems.

3.3 Application of Design Science

In Hevner et al. [100] the environment of Information Systems research is explained as the problem space consisting of people, organisations, and technologies, which define the goals, tasks, problems, and opportunities that shape business needs as perceived by individuals within the organisation. In the context of this project, Helse Vest, represented by our collaborators Berg & Serkland, together with potential users like educators and students in the medical domain, can be considered the environment. This is where the research problem was first identified. Berg & Serkland identified a real-world problem that arguably could be solved through technological innovation.

In the first activity from Peffers et al. [95], *Problem identification and motivation*, the research problem was defined. Following Guideline 2 from Hevener et al. [100], the research problem was reconsidered and narrowed down to ensure Problem Relevance. Peffers et al. [95] suggest that the objectives for a solution should be defined before the start of the development process. In activity 2 of their 6-step model, these objectives should be inferred from the problem specifications. Considering the desired outcome of the artifact as well as what is feasible to achieve in the span of a year helped shape the Research Questions seen in 1.2.

This can all be seen as part of the Relevance Cycle from Hevner et al. [102]. However, in this project, the objectives of the solution were perhaps not defined as rigorously prior to the development process, as explained in the models mentioned above. A lack of experience with developing VR applications and working with game engines, in general, made it difficult to determine what was feasible to achieve from a development perspective. Thus, the objectives of the solution were continuously reconsidered, and the angling of the research problem was adjusted accordingly even into the Design Cycle.

The nature of the Design Cycle is described by Simon [105] as generating design alternatives and evaluating the alternatives against requirements until a satisfactory design is achieved. Throughout the development process, regular meetings were held with Berg and Serkland, who evaluated the current design and helped decide which features were to be implemented in the following sprint. In addition to adding new features, their feedback was used to further refine the design. These concurrent evaluations can be seen as the testing in laboratory and experimental situations Hevner talks about when he says: "Along with Juhani, I agree that artifacts must be rigorously and thoroughly tested in laboratory and experimental situations before releasing the artifact into field testing along the relevance cycle." in [102].

At the later stages of the project, following several iterations of internal testing, the artifact was released into field testing. A number of students and educators were brought in to evaluate the VR application. The results of the testing discussed more in-depth in Chapter 5, were used to determine whether additional iterations were necessary.

Hevner [102] describes the *Rigor Cycle* as providing past knowledge to the research project to ensure its innovation. Over the course of the project, literature searches were conducted in various databases to discover whether newly performed research had been published and to gather information from the existing knowledge base. The Rigor Cycle also includes the additions of newly discovered information and design knowledge gained as a result of the DSR to the knowledge base. This thesis hopes to contribute new knowledge by answering the research questions in 1.2, developing an artifact, and discussing procedures and methods used along the way in Chapter 4.

While the project may not have strictly followed all the guidelines proposed by Peffers et al. [95] and Hevner et al. [102], the research problem was carefully identified and narrowed down to ensure relevance. The objectives of the solution were continuously reconsidered, and the design was refined based on feedback from regular meetings with stakeholders. The artifact was tested in-house before being released into field testing, where additional iterations were made based on the results. The project also contributes new knowledge by answering research questions and discussing procedures and methods used in developing the artifact.

Overall, this project has tried to create a solution to a real-world problem by creating a technological artifact and using both the development process and the artifact itself to contribute new knowledge to the environment.

3.4 Development Methodology

The exact objectives of the solution for the VR application were not clearly defined at the beginning of the project. Therefore, a flexible development methodology was needed that could adapt to changing research objectives. DSR is itself an iterative process, which means that it involves continuous improvement and adaptation. As a result, certain agile development principles were integrated into the project.

Agile development is a software development methodology that emphasises the importance of collaboration, flexibility, and continuous improvement throughout the development process [106]. The principles of agile development are centred around delivering functional software in incremental and iterative cycles, where each cycle is typically referred to as a sprint [107], illustrated in Figure 3.4. This approach allows for frequent delivery of working software that can be tested and refined to meet evolving requirements. Communication and collaboration between the development team and stakeholders are emphasised, with a focus on responding to change and adapting the development process as necessary [108].

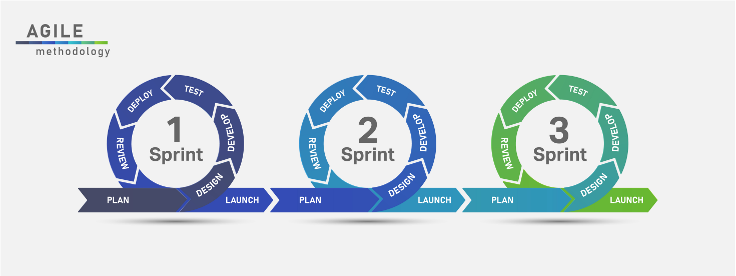


Figure 3.4: Sprint cycles in agile development. Image from Adobe Stock [109].

During the development period, 2-week sprints and regular meetings with domain experts, also serving as stakeholders, were employed at the end of each sprint. The experts tested the VR application and provided feedback about improvements and new features required for the following sprint. This was then repeated until the end of development. The chosen approach facilitated quick and efficient modifications to the VR application. It also allowed for early identification and mitigation of potential issues, reducing the risk of setbacks later in the project.

Furthermore, the emphasis on collaboration and communication between the development team and stakeholders helped to ensure that everyone involved had a clear understanding of the project goals and priorities. The agile development approach also allowed for the effective sharing of information and expertise among team members with different disciplinary backgrounds. By working together in an interdisciplinary team, members gained a better understanding of each other's roles and responsibilities and developed a shared sense of ownership and accountability for the success of the project. This facilitated better decision-making and prioritisation of tasks, resulting in a more effective and efficient development process. In addition, frequent meetings and evaluations ensured that the features being developed and refined would actually be present in the final product, ultimately reducing the development time and assuring that the requirements were met.

The integration of certain agile development principles into our DSR project proved to be effective. The flexibility and adaptability of agile development allowed for quick responses to changing development objectives, while the iterative nature of DSR provided a solid framework for continuous improvement and refinement. The focus on collaboration, communication, and frequent feedback from domain experts and stakeholders ensured that the development process remained on track and aligned with project goals. Overall, agile development and DSR seem to be able to work together in a complementary way.

3.5 Evaluation Methodology

In order to provide accurate responses to the research questions posed by this thesis, it was necessary to select an appropriate evaluation methodology. The choice of methodology is an important aspect of research design, as it directly influences the type of data that can be collected, the accuracy of the results, and the overall quality of the study.

As highlighted earlier, relying solely on either qualitative or quantitative methods would not yield optimal outcomes in this research project. Both methods have unique strengths and limitations, and therefore, a balanced integration of both approaches is often recommended to ensure comprehensive and robust research outcomes.

During the course of this project, evaluations were conducted both to enhance the design of the DSR artifact, as well as to assess its perceived usefulness. In the later stages of the study, quantitative methods were exclusively used to gather data, whereas, in the former phases, a mixed-methods approach that included both quantitative and qualitative techniques was adopted [110].

During the evaluation process, prior to testing the VR application, users were provided with a brief introduction to virtual reality technology in general and subsequently given a short walkthrough of the application. With minimal instructions, testers were then requested to explore the application independently. If too much time passed without the testers progressing through the application as intended, they would be steered in the correct direction. Additionally, any questions from the testers related to the User Interface (UI) or the application, in general, were answered. Following all evaluation sessions, testers were asked to answer a survey consisting of a System Usability Scale (SUS) [111] and a custom questionnaire.

The initial user evaluation session was conducted before the conclusion of the development phase. This provided a great opportunity to gather data that could be used to improve the design artifact, as well as data used to address RQ2. Methods like interviews and focus groups could have provided great in-depth feedback on the users' experiences. However, it was decided that an observational approach would yield sufficient results while being more flexible and less labor-intensive.

During the user testing, what users viewed was observable in real-time on a computer monitor. Additionally, a screen recording of the monitor was recorded in order to capture the users' interactions with the UI for further analysis.

The observations can be considered overt participant observations with a complete observer approach according to Oates' definition in *Researching Information Systems and Computing* [92]. The potential for individuals to change their behaviour due to the awareness of being observed during testing sessions is a valid concern. However, it was judged to be unproblematic in this instance, partly because it was the testers' interactions being recorded and not the testers themself. As such, due to the ethical questions raised by a covert approach without it adding any scientific value, a transparent overt approach was chosen, and users were made aware of the fact their interactions were being recorded.

Systematic observations were also considered. A systematic approach would require the predetermination of which events to observe. During the internal testing phase, it was observed that some users experienced difficulties in accurately clicking buttons within the menu system, as described in Section 4.8. One possible systematic approach could therefore be to record the number of times testers tried and failed to click a button. Improvements could be made, new observations could be scheduled, and the results could be compared. This would provide tangible quantitative data that could be used to argue for improvement. However, such an approach was considered to be difficult to carry out in practice. A system could be developed to automatically record these events, but this would require additional development hours.

Ultimately, the reasoning behind employing observations was to add qualitative context to the SUS, which already provides a number-based evaluation of the usability of the VR application. A participant approach allows for the collection of data without it being restricted to a specific set of events. This data can be examined and analysed in order to discover weaknesses that were not previously identified. Combining overt participant observations with the SUS provided a solid foundation for both identifying areas of improvement and measuring the level of improvement.

The SUS is a widely used method for evaluating the usability of a range of digital systems, including websites, software applications, and hardware products [112]. The SUS was first introduced in 1986 by John Brooke as a simple, standardised questionnaire that could be used to measure the subjective usability of a system by its users [111].

The SUS consists of ten questions that are designed to assess the ease of use of a system. The questions are phrased in a way that prompts the users to rate their level of agreement with statements about the system, using a five-point Likert scale that ranges from "strongly agree" to "strongly disagree" [111], as shown in Figure 3.5. By gathering user feedback through the SUS questionnaire, designers and developers can gain valuable insights into how users perceive their system and identify areas for improvement.

One of the primary advantages of the SUS is its simplicity and ease of use [112]. The questionnaire is short and easy to administer, making it accessible to a wide range of users and suitable for a variety of different types of systems. Additionally, because the SUS has been used in so many different contexts and with so many different types of users, there is a large body of research that has been conducted on its validity and reliability. This research has shown that the SUS is an effective tool for evaluating usability. Tullis [113] conducted a study comparing the SUS to four other questionnaires and discovered that the SUS requires a smaller sample size to achieve a high level of accuracy. The findings revealed that with a sample size of 8, the SUS attained approximately 75% accuracy, while the alternative questionnaires remained in the range of 40-55% accuracy at the same sample size.

Another advantage of the SUS is its ability to provide quantitative data on usability. The user answers each question according to their level of agreement as per the Likert scale, with each level of agreement corresponding to a numbered score. Strongly disagree represents 1, and strongly agree represents 5. Once a participant has answered all the questions, a single score is calculated whit a special algorithm. By averaging out the scores of all participants, it is possible to get a single number score that represents the usability of the system in question [111]. Because the SUS uses a standardised scoring system, it is possible to compare the scores of different systems or different versions of the same system to see how they stack up against one another [114]. This makes it easier for designers and developers to track improvements over time and benchmark their system's performance against industry standards.

Despite its advantages, there are some limitations to the SUS that should be considered. For example, the SUS is a subjective measure of usability and may not always accurately reflect objective measures of performance [115]. Additionally, the questionnaire is limited in its ability to provide detailed feedback on specific aspects of usability and may not be suitable for systems with highly specialised or complex functions.

Similar to the SUS, the custom questionnaire A.2, administered during user evaluations, also used a 5-point Likert scale. Participants were once again asked to rate their level of agreement with statements ranging from strongly disagree to strongly agree. However, the aim of this questionnaire was to gauge participants' perceptions of the use of VR in pharmacology education rather than the usability of a VR application. It consists of 2 closed questions gathering factual data on the respondents' familiarity with VR and their role in an educational setting and ten statements designed to collect their opinions on VR in pharmacology education.

Figure 3.5: Likert scale. Image from Adobe Stock [116].

The statements were constructed following Peterson's [117] 5 criteria for effective questions; be brief, relevant, unambiguous, specific, and objective. Additionally, to further ensure objectivity and not lead the respondents in a particular direction, statements were alternating between positive and negative perceptions. To counteract the known concern of respondents wanting to please the researcher by answering what they think is the 'desired' or 'correct' answer [92], the questionnaires were self-administered through Google Forms[118]. This also eliminates the known danger of researchers asking questions with varying tones and body language.

The data from the questionnaire could be used to compare results from students and educators, in addition to examining whether the respondents' level of familiarity with VR affects their answers. Generalizations could subsequently be made to a larger group of people. The results could also be used in future research when considering new avenues for exploring the use of VR in pharmacology education and other related domains.

In conclusion, the evaluation methodology adopted in this project includes both quantitative and qualitative methods with observations and questionnaires. Both the SUS and the custom questionnaire generated quantitative data, which would be subject to generalizations, and the observations added context to the numerical measurement of usability to identify specific improvement areas.

Chapter 4

Design and Implementation

This chapter will thoroughly discuss the design principles and implementation methods used during the development of the VR application. We will explore the specific details of the development process, including the programming languages and tools used to create the software, as well as any challenges encountered and how they were addressed. Additionally, we will cover future developments, such as potential improvements and additional features that could be added to the software.

4.1 Exploring the Application

When launching the application, users are presented with a straightforward menu consisting of three buttons: "Start", "Options", and "Exit". Each button serves a distinct purpose, guiding the user through the VR experience designed to explore pharmacology in the context of asthma. Selecting the "Start" button transports the user to the following scene, where they will have the opportunity to trace the path of medication through the airways.

At the beginning of this scene, a human figure is displayed in front of the user. In order to navigate the application, the left controller is equipped with a menu that allows the user to switch between two side menus, "Medication" and "Instructions". In the "Medication" side menu, as shown in Figure 4.1, users are presented with two choices in the form of buttons. The first one, "Simulate asthma attach", demonstrates the appearance of an asthma attack, during which the bronchial tubes contract and become filled with mucus. The second button, "Give and follow medication", initiates a journey starting in the mouth, where the asthma medication is administered, and subsequently guides the user as they follow the medicine down the airways.

The "Instruction" side menu, as demonstrated in Figure 4.2, offers three distinct options for user interaction. It incorporates two buttons that enable users to toggle the visibility of the 3D controller instructions and the accompanying subtitles for the audio clips. The top option, "Go to cross-section", transports the user to a new scene showcasing the lungs' inner workings.

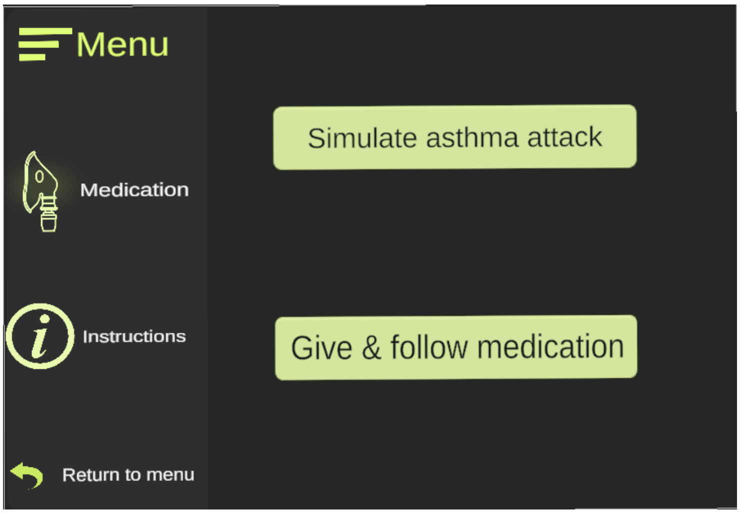


Figure 4.1: Menu page 1

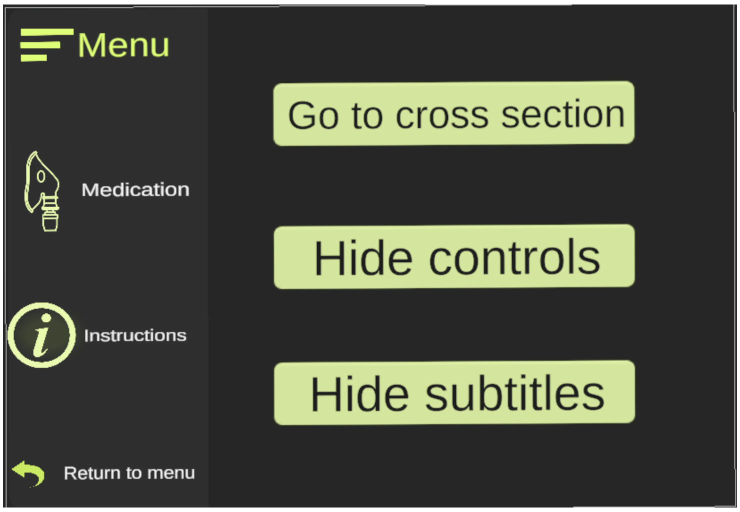


Figure 4.2: Menu page 2

In this scene, users are placed in front of a cross-section of a bronchiole, which displays the muscle cells surrounding the connective tissue. The scene offers a close-up view of microscopic particles representing the administered medication. In addition to interacting with the menu, users can also move around the scene to explore various aspects of the lungs, such as the alveoli and bronchial tubes. This interactive exploration offers a unique perspective of the lung's structure and facilitates a deeper understanding of how asthma affects these components.

The menu in this scene offers two options: "Simulate asthma attack" and "Give medication". Initially, the bronchiole is in a normal condition. When the "Simulate asthma attack" option is selected, the bronchiole begins to contract, and mucus production increases. Users can then administer beta-2 receptor agonists by clicking the "Give medication" button. The simulation illustrates the asthma medication's journey through the bronchiole, across the airway epithelium layer, and into the connective tissue, ultimately reaching the muscle cells. As a result, the bronchioles expand, and the mucus gradually dissipates.

To demonstrate how the application works, we have included a flow diagram. This provides a visual representation of the different steps involved in navigating and utilising the different functions and features of the application.

The primary menu functions as an initial point of access. The user may commence their journey by selecting the "Start" button from the primary menu, as indicated in the flow diagram depicted in Figure 4.3. The principal scene provides users with many choices, including following the selected medication as it traverses through the body, observing its effects on various organs, administering medication, and accessing the "cross-section scene" for a more in-depth comprehension of asthma attacks and medication efficacy.

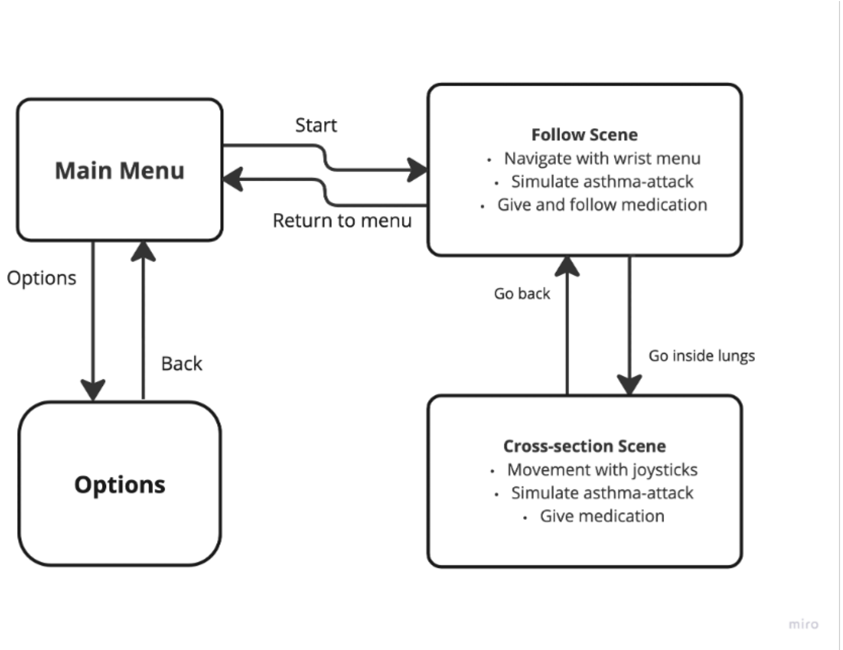


Figure 4.3: Flow Diagram

4.2 Selection of 3D Models

This section will discuss the process of choosing the appropriate 3D models to be used in the project.

In order to establish good criteria for selecting the 3D models to be implemented in the application, we had to discuss with both medical professionals and consult with technical specialists. Therefore, our selection process was a collaborative effort between the doctors we work with and the two Unity experts. Based on their expertise in pharmacology and the technical capabilities linked to the models, we ensured that the selection of models would effectively support pharmacology teaching.

One of the main considerations in selecting the models was the level of detail and anatomical accuracy required for the specific pharmacological concepts we planned to implement. The models chosen needed to accurately depict the relevant anatomy, as well as be able to animate different parts of the models. We also considered the models' visual appeal and realism to enhance the students' immersive and interactive experience.

During the selection process, we also considered the potential for future application expansion to include other diseases beyond asthma. It was essential to choose a versatile model that could cater to various pharmacological applications, ensuring that it included all vital organs and anatomical structures required for a comprehensive understanding of different diseases and their treatments.

Figure 4.4: Male anatomy model from TurboSquid

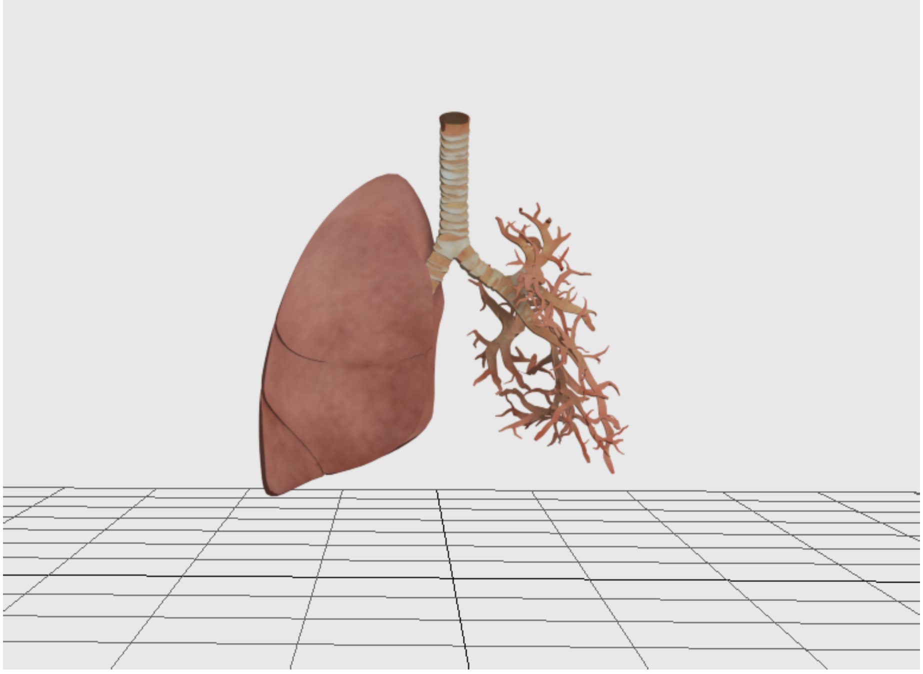


Figure 4.5: Lungs included in the full body 3D model.

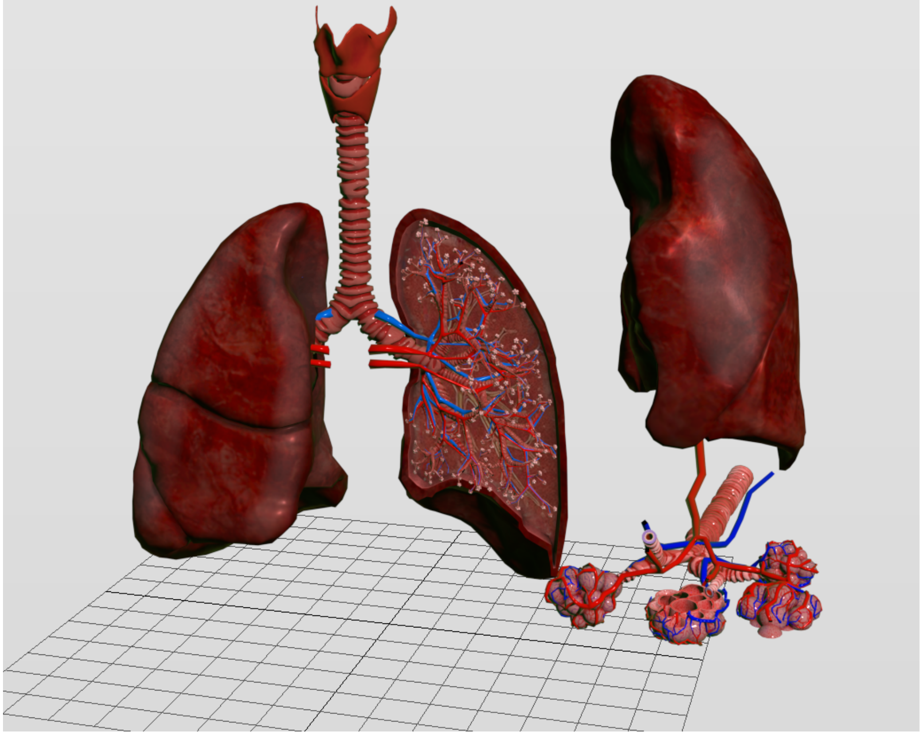


Figure 4.6: Separate lung model from TurboSquid

The models used in this project were acquired from TurboSquid [91], which offers a wide range of high-quality 3D models. From their extensive collection, we chose two distinct 3D models: one for the complete anatomy of the human body and one representing a more detailed depiction of the lungs. The decision to buy a separate lung model was made in collaboration with stakeholders after we agreed to focus on asthma as a specific disease to implement in our application. The original full-body 3D model included a less detailed representation of the lungs, which was deemed insufficient for the purpose of the application. The decision to obtain a separate, more anatomically detailed 3D model of the lungs was made with the target audience in mind. Since the aim of the application was to provide realistic simulations of the effects of quick-relief asthma medication, the intended audience was pharmacology students who would already have some knowledge of how the lungs are supposed to look. The more realistic 3D model of the lungs obtained, as shown in Figure 4.6, was deemed more appropriate for this audience.

4.3 Understanding the Structure of 3D Models

The models we acquired were fully rigged and prepared in the max format, making them suitable for editing and animation within the 3ds Max software. Fully rigged means that the models have a pre-built skeletal structure and associated control systems, allowing for easy manipulation and realistic movement of the model's various parts. The rig is usually made up of a hierarchy of bones and

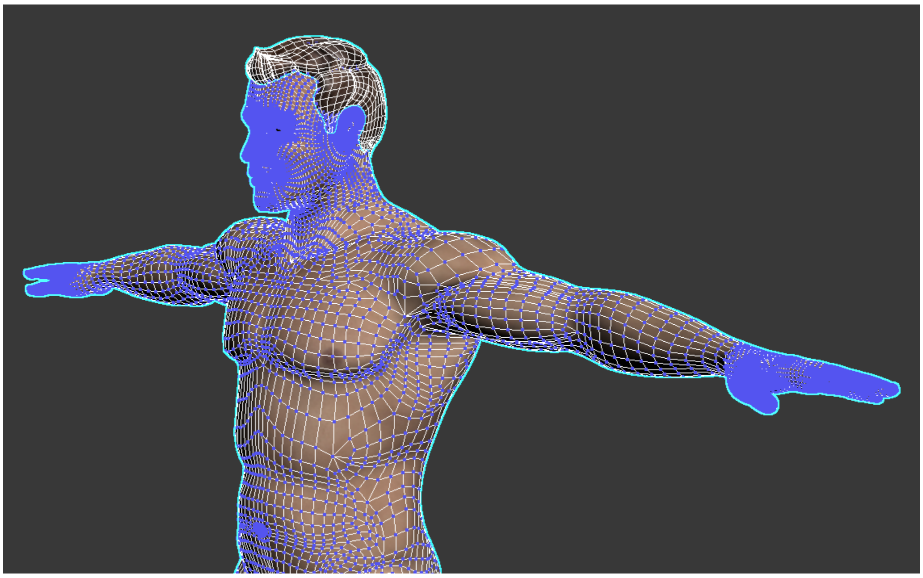


Figure 4.7: Human model displaying vertices and faces

other elements, such as constraints and controllers, which are connected to the model's geometry. This process makes animating the models more manageable, as we can focus on manipulating the rig's controls rather than manually adjusting the individual vertices of the model. However, we still had to make some manual adjustments to the individual vertices when animating on the different organs, which is further discussed in Chapter 4.5.

The human model consists of multiple groups of anatomical systems, including distinct muscle groups, the respiratory system, the skeletal system, and more. It also includes a component called Man_root_anim, which encapsulates the bone structure and defines the relationships between all the components within the model.

4.4 Preparing the 3D Models

When preparing the 3D models for the project, an essential aspect was ensuring that they had a visually appealing and high-quality appearance. Creating a smooth and realistic representation of the models would contribute to a better user experience and make it easier for users to recognise and relate to the anatomical structures. In the early stages of the project, a large part of our work was dedicated to addressing the various challenges we faced in this process.

One of the main challenges we encountered was the models initially having a low-poly appearance. In 3D modeling, the term ”low-poly” refers to a model with a relatively low number of polygons, the flat surfaces that make up the model's mesh. This results in the model looking angular and having a poor resolution, as the shapes that compose it are less refined and more visibly distinct. Addressing this problem was essential before the models could be effectively integrated into our application.

The solution to this issue was to use a modifier called **Meshsmooth** in 3ds Max. Meshsmooth is a powerful tool that refines and smooths the geometry of a 3D model by subdividing its polygons, thereby creating a higher-resolution mesh. We experimented with this modifier by adjusting the smoothness value, which controls the level of detail added to the model. This process had to be performed on each component of the models, making it quite time-consuming. It was especially so for the full human model, which consists of numerous parts.

Applying the Meshsmooth modifier led to a significant improvement in the appearance of the models, allowing them to be exported to Unity with a much higher resolution. However, later in the project, we experienced performance issues due to the increased number of polygons and vertices generated by the smoothness value. To address this issue and improve the application's performance, we had to adjust this value downwards, reducing the number of polygons and vertices while still maintaining a satisfactory level of detail.

Another challenge we encountered while working with the 3D models involved the misalignment of inner organs and anatomical components after applying the Meshsmooth modifier. When the smoothness value was adjusted to enhance the model's appearance, some of the inner structures ended up protruding outside the model's skin, particularly when attempting to animate the movements of various body parts. This issue resulted in muscles and skeletal parts sticking out of the skin, creating an unrealistic outcome.

To address this problem, we had to examine some of the components of the models and manually adjust the positions of the protruding organs, ensuring they remained within the skin boundaries even during animations. This process involved tweaking the vertex positions, altering the rigging, and refining the skinning to better conform to the smoothed geometry.

However, this issue became less critical as the project progressed since most of the game experience occurred inside the airways and lungs rather than outside the model. Furthermore, we have not included any animations involving body movements, which means that the problem of protruding inner organs has become less relevant to the overall user experience.

4.4.1 Combining the Models

Due to the decision to focus the application on the effects of quick-relief asthma medication, the anatomical quality of the lungs included in the full body 3D model, shown in Figure 4.5, was deemed inadequate for the project's purposes. Consequently, the 3D model shown in Figure 4.6, specifically designed to represent the anatomical structure of the lungs, was obtained. Implementing this separate, highly detailed lung model enabled the creation of more realistic simulations that were considered better suited for pharmacology students.

In order to integrate the newly obtained lung model, certain adjustments were necessary. Due to the difference in dimensions between the old and new lung models shown in Figure 4.8, simply incorporating the new model into the full body was not feasible. Furthermore, the new lung model did not encompass a full lung for the left side; it only displayed a cross-sectional view of the lung, as shown in Figure 4.6. To address the latter issue, the right lung was simply

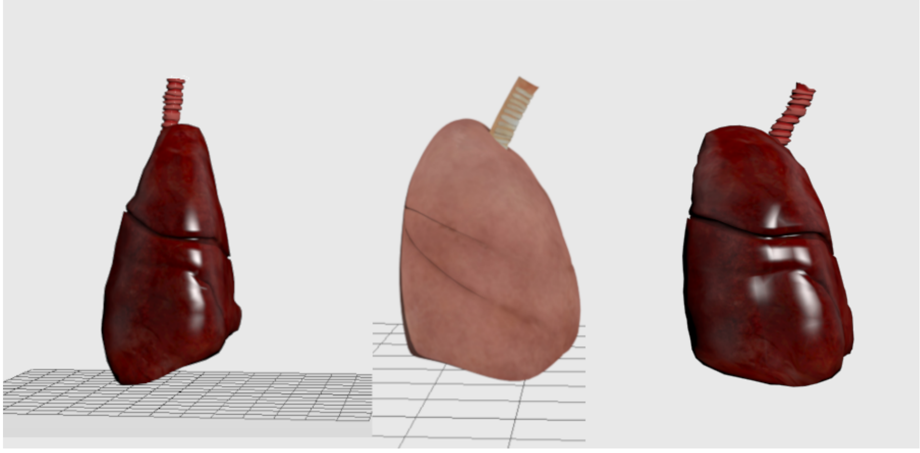


Figure 4.8: Side by side comparison of the two lung models and the adjusted separate lung model.

duplicated and mirrored, then positioned to align with the other model components replacing the left lung. However, the left lung cannot be an exact mirrored copy of the right one due to the anatomical placement of the heart on the left side of the human body. Therefore, in order to incorporate the new lung model into the full-body model, the shape of the left lung had to be adjusted. To address this issue, the vertices of the left lung model were manipulated using several modeling tools in 3ds Max to achieve a shape that was anatomically accurate while still fitting seamlessly into the full-body model. Figure 4.10 displays the adjusted lung model with the integrated heart to demonstrate the proper anatomical placement of the heart in relation to the lungs.

The difference in dimensions between the included and separate lungs was fixed with a similar approach. 3ds Max provides a variety of sculpting tools that allow users to manipulate individual vertices or groups of vertices to achieve the desired shape of the 3D model. These sculpting tools include brushes that can be used to push and pull vertices, as well as smooth, flatten, and pinch tools for more precise adjustments. The shape of the separate lungs was carefully modified to resemble the shape of the included lungs. This was necessary to prevent any possible intersection with other components of the full-body model. The rightmost lungs in Figure 4.8 show how both the lungs' shape and the trachea's angle were adjusted to facilitate the combination of the 3d models. Figure 4.11 shows how the newly adjusted lung model fitted in between the organ systems of the full body model.

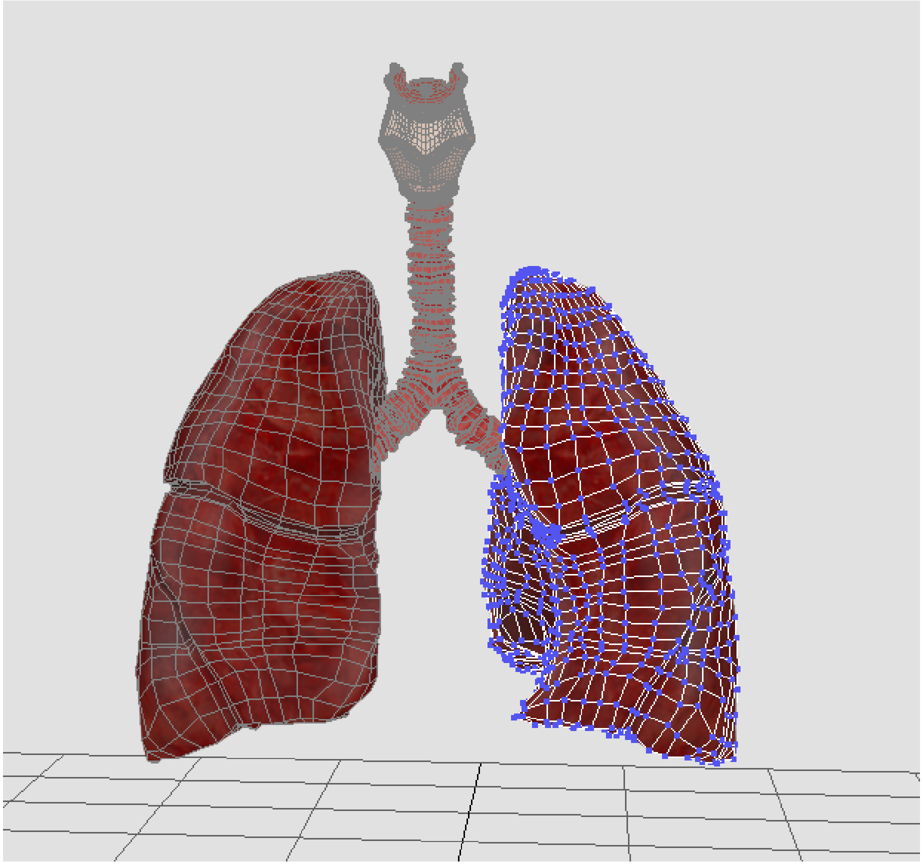


Figure 4.9: Separate lung model being modified to fit with heart.

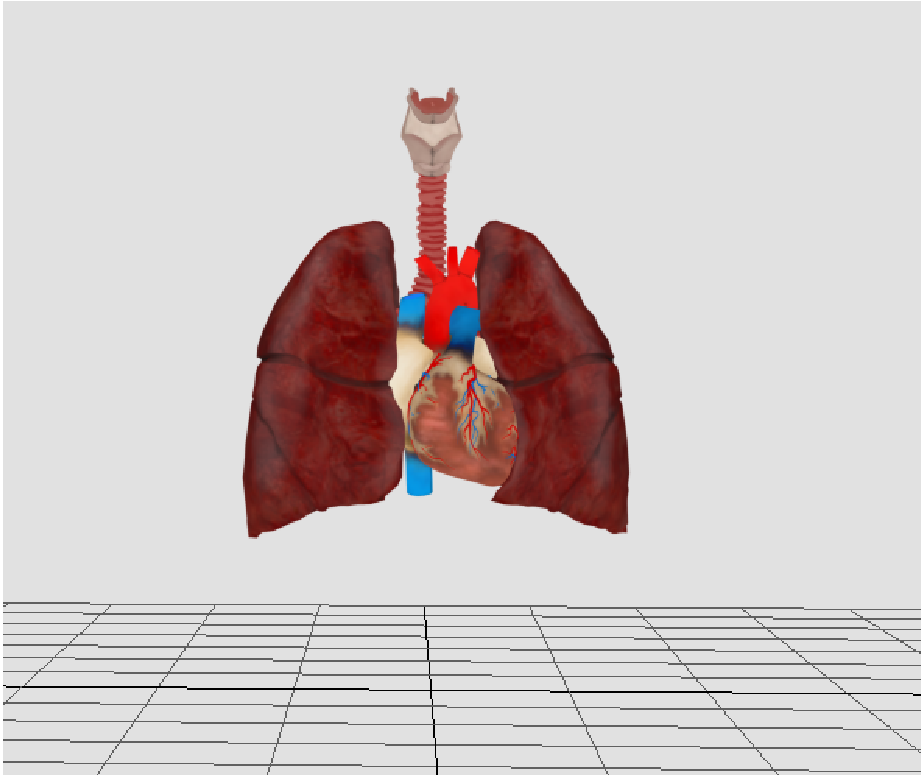


Figure 4.10: Separate lung model modified to fit with heart.

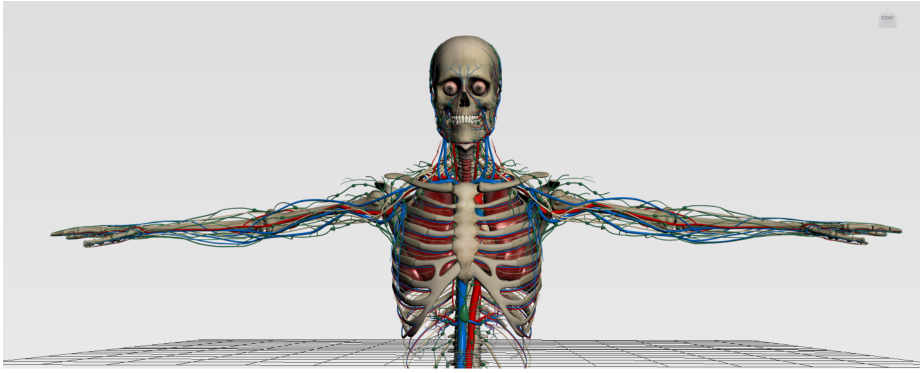


Figure 4.11: The adjusted lung model fitting in with all the components of the full body model.

4.5 Animation of the 3D Models

A significant part of the development process involved creating the required animations for use in the application. In this section, we will examine the various techniques and tools employed at each stage of the animation process, from the initial stages of preparing the 3D models to the final implementation of the animations in Unity.

Both Unity and 3ds Max offer tools to make animations. In Unity, this process generally involves using the **Animation** window along with an **Animator** component to design and manipulate animations. It may also include scripting to control the transitions and interactions between animation states. In terms of animating our human model, as mentioned in section 4.3, it features a prebuilt skeletal structure that can be utilised within Unity. This facilitates the efficient creation of animations for a range of body parts, such as executing an arm movement to grasp an object. By taking advantage of this, it becomes easier to create natural and fluid motion sequences without the need for manual adjustments to individual vertices.

However, this approach only applies when animating movements that are part of the skeletal structure. For animations aiming to alter the shape of specific body parts within the model, it becomes necessary to adjust the vertices of the mesh itself. 3ds Max is best suited for this task, as it offers a wide range of modeling and animation tools designed explicitly for this purpose. In 3ds Max, vertices, edges, and polygons can easily be manipulated using its comprehensive set of tools, and complex animations can be created with keyframes or procedural methods. While Unity does have some mesh editing capabilities through scripting or third-party plugins, it is not designed to be a full-featured 3D modeling animation software like 3ds Max.

We explored various approaches to enhance the user experience during the development process. One such attempt in the early stages was to implement an animation where the patient/model picks up an inhaler. This was accomplished in Unity by creating an animation clip in the Animation window and then linking it to an Animator component, which controls the playback of the animation. However, as the project progressed, our focus shifted more towards animating the events occurring within the lungs during an asthma attack. As a result, the importance of the animation illustrating the patient retrieving an inhaler was deemed less critical in comparison to other aspects of the project.

Following the completion of the inhaler-picking animation, our animation efforts shifted primarily towards visualising the medication's effects on the airways and simulating the symptoms of an asthma attack. There were primarily two necessary animations to consider: one to cause the bronchial tubes in the lungs to contract during an asthma attack and another to expand them when medication is administered. As mentioned in Chapter 4.7, our application consists of two main scenes. The first scene features the full body model, including the associated lungs, while the second scene contains these lungs in addition to the cross-section model.

For the human model, the process of animating the lungs was carried out in 3ds Max. The goal was to create an animation where the bronchial tubes contracted

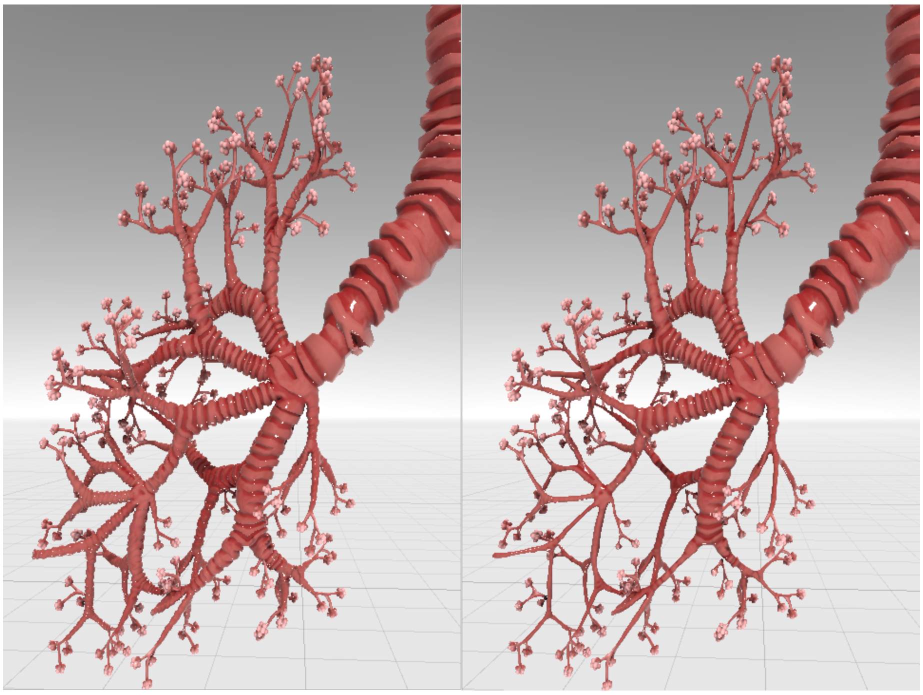


Figure 4.12: Contraction of the bronchiols animated in 3ds max. Normal on the left and contracted on the right.

and one where they expanded. To achieve this, we began by cloning an instance of the model component we wanted to animate, the bronchial tubes, using the Scene Explorer in 3ds Max. This new copy of the component allowed us to edit its meshes without affecting the original.

Various tools in 3ds Max can be used to modify the mesh, such as **PolyDraw** and **Paint Deform**. PolyDraw lets the user create and edit polygonal models interactively, while Paint Deform allows for the manipulation and deformation of a mesh object's geometry using a brush-like interface. We used several of these brush-like tools to carefully adjust the mesh, achieving the desired contraction effect in the bronchial tubes.

When satisfied with the results, the next step was to add a Morpher modifier to the original component we cloned. The Morpher modifier is a powerful tool that allows for smooth transitions between different mesh shapes, called morph targets, by interpolating the vertex positions. Within this modifier, we accessed the Channel List setting, adding a new channel and connecting the modified mesh clone as a morph target. This linked the modified mesh to the original model component, enabling us to create a seamless transition between the bronchial tube in its normal state and its contracted state.

Now, with two different states of the model, we proceeded to create the animation. Using the **Time Slider**, we controlled the timing of keyframes in the animation. At frame 0, we enabled **Auto Key** mode, which automatically records keyframes for any changes made to the model object. Finally, we set a

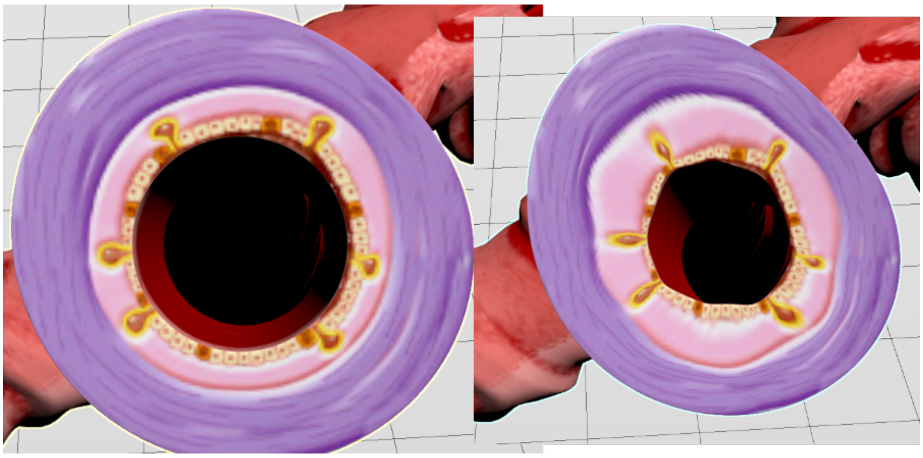


Figure 4.13: Original model of cross section & attempt to contract the bronchiole tubes.

keyframe at the start of the animation, with the model in its original form.

To create the contract animation, we moved the time slider to the midpoint of the animation clip's duration on the timeline. At this point, we set the target value for the modified mesh to max inside the Morpher modifier, allowing the original object to fully adopt the shape of the target object. Then, moving the time slider to the end of the animation, we set the target value to min, which returned the object to its original shape.

While creating multiple animations for the 3D models, several possibilities were examined within the 3ds Max. The goal was to find a method that would allow the export of FBX models containing multiple separate animation clips. However, no straightforward or efficient way was discovered to achieve this. After searching various discussion forums, it became apparent that 3ds Max may not be ideally suited for this purpose. Therefore, we concluded that the most feasible approach was to create all the animations on the same timeline within 3ds Max. This approach involved creating a single, continuous animation clip that encompassed all the required animations.

By doing it like this, we created both animations in a single clip. This was later exported to Unity, where we later processed and divided it into separate animations, which we will further discuss in section 4.6.

The animations created for the full-body model, shown in Figure 4.12, lungs could be utilised in both of the Unity scenes to simulate the contraction of the bronchial tubes. However, when animating the cross-section model, we had to adopt a slightly different approach due to its higher level of detail in the texture. This model displays a cross-section of the bronchiole, which requires a more complex animation process. The model would be used to visualise what happens when the airways contract, specifically the contraction of the muscles surrounding the tubes and the expansion of the soft connective tissue located inside the bronchiole tubes.

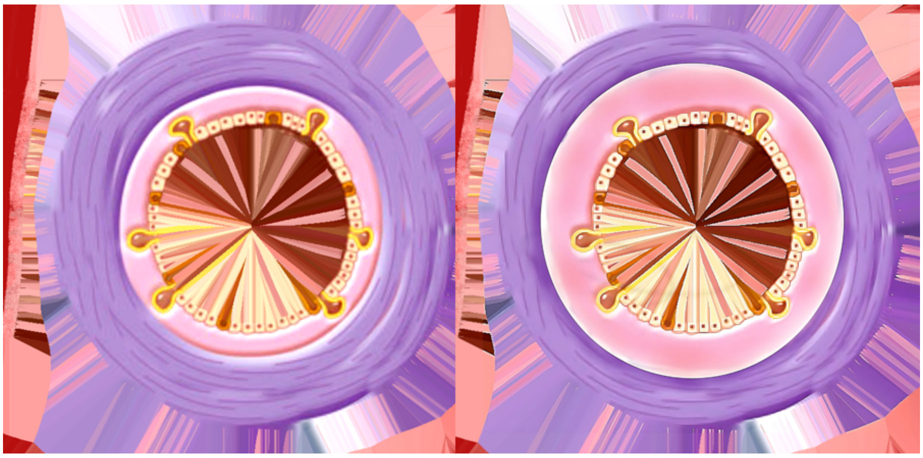


Figure 4.14: The cross-section portion of the original texture and the altered texture side by side.

We made several attempts to animate the contraction for this model. Utilising the same techniques as those described above, we encountered complications with the texture mapping of the muscle cells and the connective tissue layer. As we utilised modeling tools to contract the bronchial tubes, we observed that the texture became distorted or stretched, resulting in a reduced level of visual clarity and realism. The underlying cause for this problem was attributed to the connective tissue layer in the cross-sectional model being relatively thin compared to the muscle layer. As demonstrated in Figure 4.13, we attempted to create an animation that portrayed the swelling of the connective tissue layer during an asthma attack and the contraction of the muscle cells resulting in the narrowing of the bronchioles. To achieve this, we used the pinch/spread tool in 3ds Max to manipulate the vertices of the cross-sectional model. Specifically, we spread the vertices in the connective tissue layer to depict swelling. Then we pinched all the vertices of the cross-section to simulate narrowing caused by muscle cell contraction. However, this approach resulted in texture distortion and stretching due to the thinness of the connective tissue, resulting in fewer vertices in the original cross-sectional model.

To address this challenge, we opted to modify the texture that accompanied the 3D model. More precisely, we utilised GIMP, a photo editing software, to alter the included texture. By using drawing tools available in GIMP, we were able to expand the size of the connective tissue layer. Figure 4.14 showcases the original texture on the left and the modified texture on the right. Applying this new texture to the model would mean more vertices in the connective tissue layer, making it easier to spread them without distorting the other components of the model. Figure 4.15 exemplifies how our approach enabled us to maintain high-quality texture while animating the expansion of the connective tissue with minimal distortion to the other components, consequently enhancing the animation's realism.

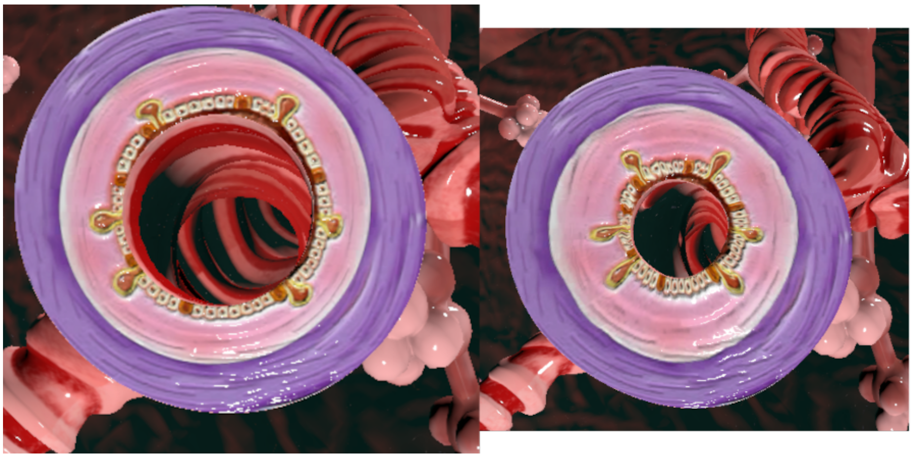


Figure 4.15: Animated contraction of the bronchial tubes with the new texture.

4.6 Implementation in Unity

The goal of this section is to provide a detailed overview of the implementation and development process in Unity. This section focuses on the practical aspects of incorporating the 3D models into the Unity platform, as well as setting up the virtual environment. We will also cover the technical considerations, such as optimising the models for VR and how to ensure a smooth experience in the VR headset.

The implementation process started with the initial setup of a new Unity project. We decided to use Unity version 2021.3.7f1[LTS], as it provides long-term support and stability, ensuring that our project would be compatible with future updates and enhancements.

The initial focus was on setting up the Unity project to support interaction in VR. This involved adjusting various settings, such as enabling virtual reality support in the player settings, setting up input systems for VR controllers, and configuring the camera rig. In order to support multiple types of VR headsets, we opted for OpenXR as our VR platform. OpenXR is an open standard for VR and AR applications, allowing developers to create software that is compatible with a wide range of devices without being locked into a single ecosystem [119]. This ensures that our application can be accessed by a larger audience, regardless of their choice of VR hardware.

The OpenXR plugin includes a component, the XR Rig, that provides a framework for managing VR and AR experiences across a range of devices. Essentially, the XR Rig serves as an intermediary layer between the physical tracking of the VR/AR hardware and the virtual tracking of the Unity game engine. It accomplishes this by providing various components that are designed to manage the relationship between the VR/AR hardware and the virtual world of the game engine. These components include the XR Rig camera, which handles the rendering of the virtual environment, as well as the XR Rig controller, which manages the user's interaction with the virtual world. Additionally, the XR Rig includes a range of settings and configurations that allow developers to

Clips	Start	End
shrinkBronchialTubes	0.0	50.0
expandBronchialTubes	50.0	100.0

shrinkBronchialTubes

Length 1.667

30 FPS

Start 0

End 50

Figure 4.16: Animation-clips in Unity

customise the VR/AR experience to suit the specific needs of their project.

To facilitate 3D and UI interactions in VR, the XR Interaction Toolkit was used. The toolkit is a package for Unity that provides a suite of components, tools, and assets for creating interactive experiences in VR and AR [120]. The toolkit is designed to work with a range of different input devices, including hand controllers, gaze-based systems, and more traditional input methods like keyboards and mice. With the XR Interaction Toolkit, developers can easily create interactive objects and manipulate them in a natural and intuitive way, using a range of different interaction types, such as grabbing, throwing, and scaling.

Implementing the 3D models into Unity was a critical aspect of the project. After preparing the models in 3ds Max, we exported them into Unity in FBX format, which is a widely supported and flexible file format for 3D models.

As discussed in section 4.5, the decision was made to create all the animation sequences collectively in a single clip within 3ds Max. This complete animation clip was then imported into Unity, where it was divided into separate clips. This was found to be the most effective method.

This process of splitting animations within Unity offered greater flexibility and control over the animations. Upon exporting the models to Unity, the FBX file contained the composite animation clip. From this point, the Unity interface allowed for easy selection and manipulation of the imported model. To divide the animation clip, the ”Animation” tab was accessed in the Inspector window, which revealed a list of all the clips contained within the FBX file. This list was initially populated with a single animation - the combined clip exported from 3ds Max. The ’Start’ and ’End’ frame numbers were adjusted to match the desired range of each clip. To split this clip into separate animations, the ’plus’ icon was clicked, and a new clip was defined, as demonstrated in Figure 4.16.

4.7 Scene and Level Design

The application is divided into multiple scenes, each focusing on a particular aspect of the asthma disease. To provide a comprehensive understanding of the various processes involved in asthma medication, we have structured the application into two primary scenes.

The first scene emphasises the journey of the medicine as it enters through the mouth, travels down the airways, and approaches the lungs. This scene contains the full-body 3D model, which has been carefully scaled up to make the tiny details within the respiratory system more visible and easier to observe.

The second scene is designed to provide a closer look at what happens inside the lungs. In this scene, only the lungs from the previous model are included, with the rest of the body parts removed to enhance performance. To effectively showcase the intricate details within the lung models, they have been significantly scaled up, enabling users to closely examine the inner workings of the medication as it travels through the bronchial tubes and binds to the mucous membrane.

4.8 User Interface and Interaction Design

During development, we experimented with different approaches to create an accessible and user-friendly menu that would enhance the experience. To enable the user to intuitively navigate the application's features, such as following the medication or navigating between the different scenes, we implemented a wrist-mounted menu that is attached to the left controller. The menu consists of labels and visual icons for each option to simplify the user experience and enable efficient navigation between different functionalities. This menu consistently follows the player as they move around exploring the scene, ensuring easy access to the options at all times. The right controller serves as a tool for selecting and interacting with the various options in the menu, as illustrated in Figure 4.17. This design choice ensured that users could comfortably interact with the application while maintaining a sense of immersion in the virtual environment.

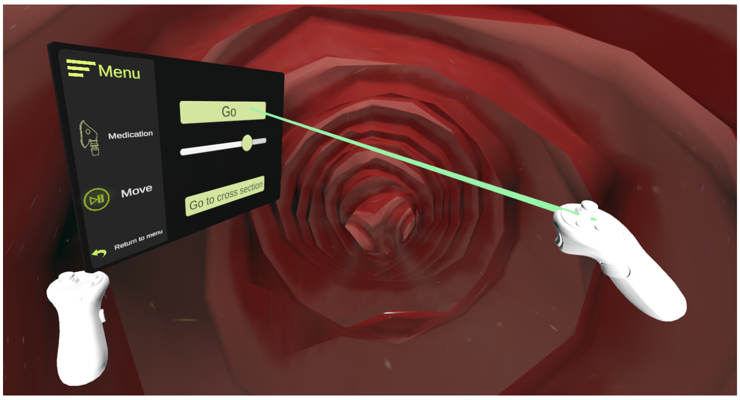


Figure 4.17: Menu interaction with hand-controllers

In the early development stages, the menu offered a more extensive range of options, divided into four different side menus. One of them provided options to toggle the visibility of various anatomical systems in the body. However, as we shifted our focus toward asthma medication and the simulation of an attack, this feature was deprioritised. Another menu option provided users with the ability to toggle the sound of the heartbeat and breathing on or off. However, during the development process, it was decided to set the sound to "on" by default and remove the option to disable it to reduce user confusion and streamline the user experience.

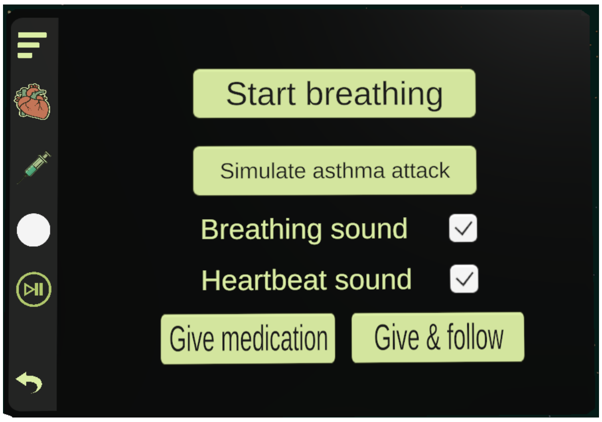


Figure 4.18: Old menu

During user testing, we discovered that many participants found the multiple medication options confusing. As illustrated in Figure 4.18, the original design had a "Give Medication" button for administering the medication and a separate "Give and Follow" button for administering while following the medication. To resolve this issue, we consolidated the options into a single button that would automatically administer and follow the medication down the airways, as well as another button to simulate an asthma attack. This change, among others, significantly simplified the final menu, which can be seen in Figure 4.19, resulting in a more user-friendly interface with clearer, more focused choices.

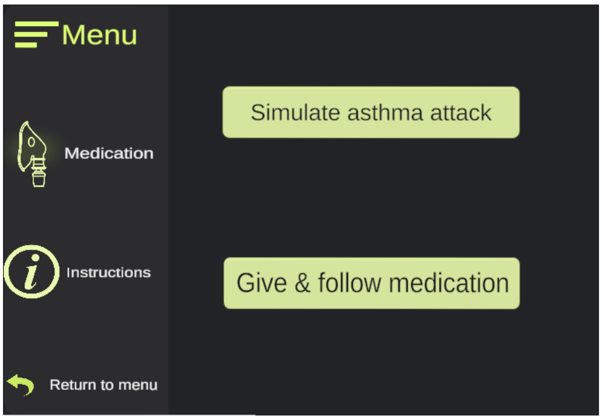


Figure 4.19: Final menu

During the later stages of development, additional simplifications were introduced to the UI. It was found that the point-and-click interface was unsuitable in certain circumstances. In particular, controlling their speed with the slider in the wrist menu was a challenge for users, as it required precise control of the virtual cursor. This detracted from users' ability to explore and experience the virtual environment fully. Therefore, a new approach was implemented, where the speed was controlled through the user's physical interaction with the grip buttons on the hand controllers. This solution was found to be more natural and intuitive for users and allowed for a more immersive experience. As shown in 4.20, instructions in the form of 3D elements were attached to the hand controllers to help users get familiar with the button setup.

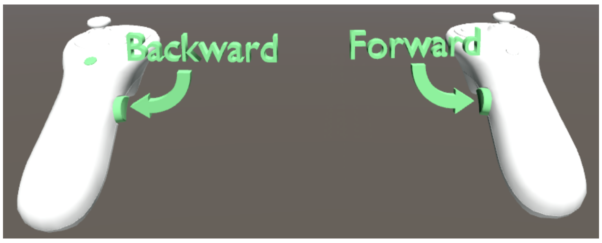


Figure 4.20: Navigation with 'Grip' buttons on hand controllers

In terms of implementation in Unity, the menu is composed of multiple GameObjects that create the UI. At the top of the hierarchy is a Canvas GameObject, the parent element that holds all the UI components that form the menu. Separating the visual design from the functional aspects, a tablet-shaped object with a black material serves as the background for the menu.

The second child of the Canvas component is called Display, which is responsible for managing the various side menus and the content of each panel. It contains a GameObject called SideMenu, which includes all the different buttons and logos for the side menu itself. Furthermore, the other components under Display are responsible for the content of each panel that the user can switch between, such as the "Medication" and "Instructions" menus. They primarily consist of all the buttons belonging to the current panel.

One of the essential elements in creating a visually appealing UI is text rendering. For our project, we chose to use Text Mesh Pro (TMP), a powerful and versatile text rendering solution in Unity. TMP provides improved text quality, flexibility, and customisation options compared to the standard Unity Text component, making it an ideal choice for our application. We employed TMP in various parts of our menu, such as button labels, panel headers, and informational text.

4.9 Audio Integration

Incorporating audio into the virtual reality experience plays an important role in enhancing user immersion and providing a more engaging and realistic environment. The initial stage of audio integration involved a process of sound selection and design, in which careful consideration was given to the specific sounds to be employed. The audio content employed within the application can be categorised into three distinct components, namely, breathing audio, heartbeat audio, and narration audio.

In Unity, audio is integrated into a scene through the use of **Audio Sources** and **Audio Listeners**. An audio source component in Unity is responsible for emitting sound within a scene and is attached to the GameObject representing the source of the sound. An audio listener component is responsible for receiving the sounds and processing the audio based on its position and orientation relative to the audio sources.

Within our project, significant emphasis was placed on integrating different breathing sounds. The inclusion of normal exhalation and inhalation sounds serves to represent the standard respiratory process, where air flows freely in and out of the lungs without any hindrances. In contrast, asthmatic breathing is characterized by distinct wheezing sounds and a sensation of breathlessness. These specific audio cues play a crucial role in establishing a reference point for the user and aid in distinguishing between the characteristics of healthy and asthmatic lungs.

The heartbeat sound is another key audio element in our project. This rhythmic sound represents the continuous pumping of blood through the circulatory system. The primary objective of incorporating the heartbeat audio was to enhance the level of immersion experienced by users, aiming to emulate a believable sense of being inside an actual human body.

An audio source in Unity can be categorised as 2D, 3D, or it can lie on a spectrum between the two. When a source is designated as 3D, it signifies that it is spatially positioned within a three-dimensional environment, enabling sound attenuation based on its virtual location relative to the listener, thereby creating a realistic auditory experience that simulates depth and positional audio cues. In the context of virtual reality, 3D sounds can help create a more realistic experience by allowing users to perceive the direction and distance of sound sources within the environment.

Audio sources in Unity offer a variety of 3D sound settings that can be fine-tuned to create the desired sound effects. One such setting used in our application is Max Distance, which defines the range within which a sound can be perceived. Both the breathing sound and the heartbeat sound takes advantage of this setting. The Max Distances of the Audio Sources, coupled with a customised Volume Rolloff, were meticulously adjusted to precisely align with the initial point of entry into the mouth, as shown in Figure 4.21. This deliberate configuration ensures that users can not hear the breathing or heartbeat until the precise moment they enter the mouth, thereby emphasising the immersive sensation of traversing into the human body.

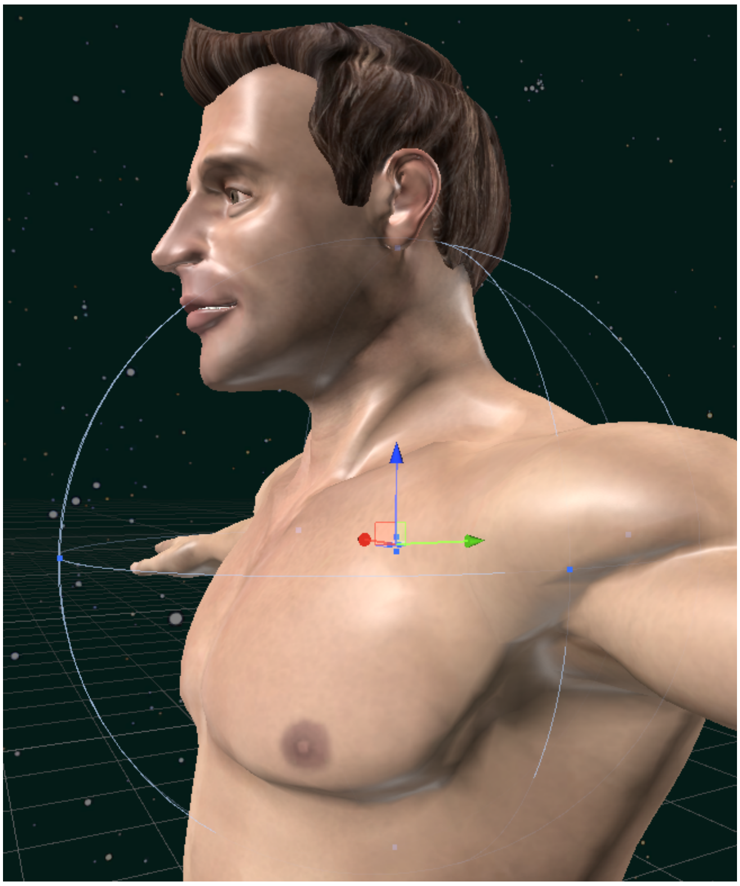


Figure 4.21: The sphere illustrates the maximum distance within which the breathing sound is audible.

For the breathing audio, the Volume Rolloff was configured in such a way that the volume of the breathing was constant within a certain distance, in our case, the distance from the audio source to the mouth of the 3D model. This decision was motivated by the recognition that the sound of breathing is not solely generated within a single localised area of the lungs; instead, it emerges as a collaborative result of various structural components within the respiratory system [121] [122]. Consequently, the significance placed on the spatial placement of the breathing audio source was relatively diminished in comparison to other audio elements.

In contrast, particular attention was devoted to the precise spatial placement of the audio source for the heartbeat sound. The heartbeat source was positioned at the corresponding anatomical location of the heart. As a means to enhance the immersive nature of the experience, the Volume Rolloff for this specific audio source was configured in a linear fashion. This implies that the volume gradually diminishes as the listener moves farther away from the audio source. In practice, this configuration enables a gradual intensification of the heartbeat sound as the user advances along the journey of the medicine through the airways, drawing closer to the heart.

The concluding audio component, namely the narration audio, employed a straightforward 2D approach. This decision stemmed from the requirement for audibility of the narration throughout the traversal of the lungs in the Follow Scene and during the unrestricted exploration within the Cross-Section Scene, rendering it a suitable and appropriate solution for achieving the intended objectives.

4.10 Breathing System

The breathing audio played a big part in the efforts to give the users the feeling of actually being inside a human body. In addition to the audio, users can also see a visual representation of the breathing. This added layer of information should make it easier/more intuitive to understand what is happening and make the application more accessible for hearing-impaired users.

When creating the look of the breathing visualisation, we considered many approaches. Initially, we envisioned clusters of spheres, with colours alternating depending on whether the model is inhaling or exhaling, where each sphere represents a single air particle. However, through internal testing and feedback from Berg and Serkland at HUH, it was concluded that this approach could be distracting to the users and difficult accurately depict. Instead, we opted for a look resembling how the wind is portrayed in animations and cartoons.

The first renditions were created with a combination of Unity's Trail renderer component [123] and an asset from the Unity Store called Bézier Path Creator (BPC) by Sebastian Lague [124]. Lauge describes the BPC as an intuitive and lightweight editor for quickly creating smooth paths in the editor. The asset allows "PathFollowers" to travel along these paths. The Trail renderers allow you to draw *trails* represented as lines and other shapes behind moving GameObjects. Length, thickness, and colour are just some of the customisable attributes.

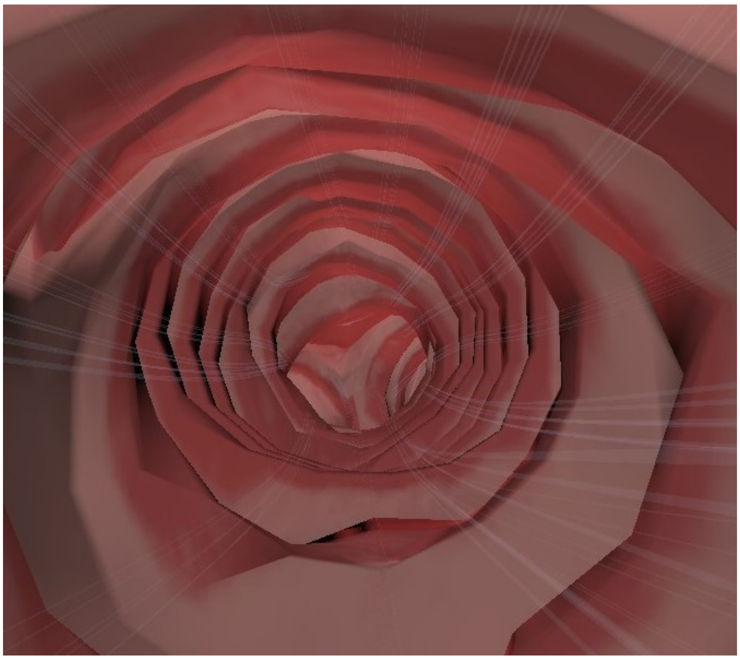


Figure 4.22: Breathing visualisation created with Trail renderes

Adding trails to invisible GameObjects moving along paths through the airways gave results that could be considered passable, as seen in Figure 4.22. However, the visual effects produced by these initial designs did not meet the realistic standards that we were striving for. Moreover, the visual trails generated by these designs could potentially become intrusive to the users' experience. In the lower lung regions, where the airways are narrower, and the user is significantly closer to the trails, users could sometimes experience the sensation of being hit in the face by them.

Figure 4.23: Breathing visualisation created with Particle systems

By pivoting to an approach using Unity's Particle system and using videos of cars being tested in wind tunnels as a reference, we were able to produce a look more resembling what we had in mind, see Figure 4.23. The particle system is a powerful tool for creating visual effects such as explosions, smoke, fire, and more. It allows developers to generate and control large numbers of particles in real-time. By changing the material and size of the emitted particles and aligning them to form a line, they start to resemble a single trail of smoke. Attaching multiple adjusted particle systems to paths that lead them through different routes in the airways creates the illusion of air being inhaled and evenly distributed through the lungs.

In Figure 4.24, each of the green lines is a path created with the BPC. The paths all start at roughly the same point, and they are all centred around the path to a specific set of alveoli, which is the path the user travels on. As one moves down the airway, the level of branching increases, resulting in more paths breaking off.

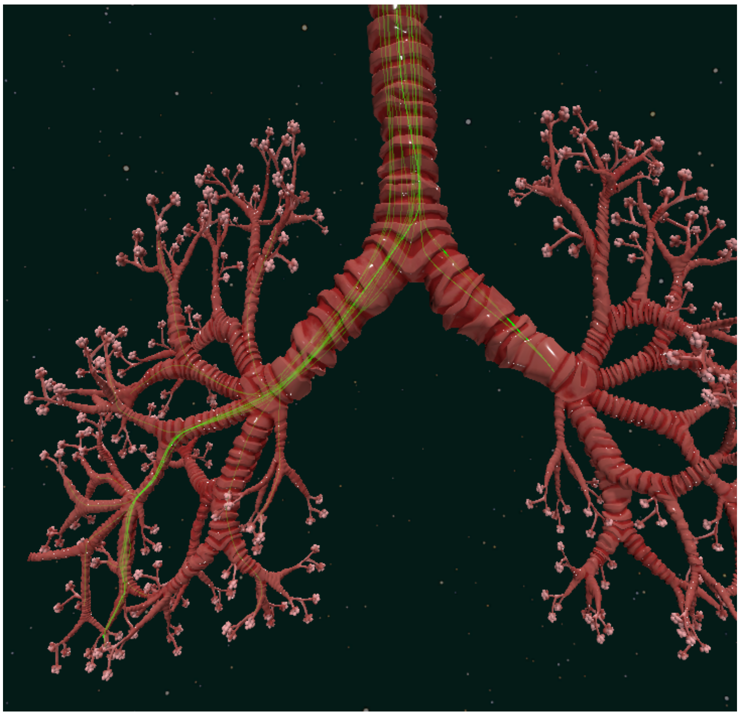


Figure 4.24: Breathing visualisation created with Particle systems

The visual representation works closely with the integrated breathing audio to synchronise them. The breathing audio source alternates between to AudioClips [125], one for inhaling and one for exhaling. When one clip finishes playing, the audio source is changed, and the next clip starts playing. This creates a continuous loop of inhaling and exhaling that can be heard as soon as the user has entered the mouth. If the user does nothing, the loop will continue playing as normal. However, if the users choose to simulate an asthma attack, the sound clip for the exhale AudioClip is changed to a clip recorded from a person with asthma.

The difference in the sound of breathing in a person with an asthma attack compared to a healthy person is most noticeable during the exhale. Therefore, only the source of the exhale AudioClip is changed during the asthma simulation.

Earlier iterations of the breathing systems included an approach to the breathing audio where a single sound bite continuously played, including an inhale followed by an exhale. This sounded fine when simulating normal breathing and asthma breathing independently. However, it did not sound good when switching between them. A user might choose to simulate an asthma attack at the end of an inhale. In older iterations, this would result in the immediate cutoff of the current inhale, and a new inhale would start playing, meaning that the simulated human would inhale twice in a row which is not natural.

The new technique where inhaling and exhaling are independent sound bites allows for a more seamless transition between normal breathing and simulated asthma breathing. To illustrate with the same example as above, if a user triggers the "simulate asthma attack" function at the end of an inhalation, only the subsequent exhalation clip would be modified, ensuring that the ongoing inhalation would play out and be followed by a wheezing exhalation. The same would occur when transitioning back to normal breathing from simulated asthma breathing.

In addition to maintaining the naturalistic quality of the breathing sound, synchronicity with the breathing visualisation presented at the beginning of the section was deemed essential. Specifically, the inhalation sound should correspond with the depiction of air entering the lungs, while exhalation should accompany the depiction of air being expelled from them.

Initially, the airflow was programmed to travel back and forth along the predetermined paths through the airways. Upon reaching the end of the path, it would switch direction and travel back along the same path, repeating the cycle. Attempts were made to adjust the speed of the airflows to synchronise it with the inhales and exhales of the breathing audio. However, achieving perfect alignment proved challenging due to the difficulty in accurately matching their timing. Furthermore, even minor discrepancies in timing became increasingly prominent over time.

This issue was addressed with a new approach which involved dividing the airflow into two separate GameObjects that moved along the same path. In this method, one GO moved forward as the inhale sound played, while the other moved backward as the exhale sound played. The pathFollower script included in the BPC asset was modified to take in an AudioSource. The modified pathFollower script is programmed to consistently monitor which AudioClip is being played on the AudioSource, that is, whether it is inhale or exhale, and subsequently initiate movement along the BPC path when the appropriate sound is detected. A boolean within the script controls whether a GameObject should move during an inhale or exhale phase.

4.11 Movement System

One of the key aspects of the VR application was the movement mechanics. An advantage hypothesised for VR applications over traditional video, or even 3D video, is the user's ability to navigate and explore the virtual environment freely and at their own pace. In order to provide users with that freedom, it was imperative to implement an adequate and efficient movement system.

The application comprises two distinct scenes that together form the core of the simulation, namely the follow-scene and the cross-section scene. Additionally, the application comprises a main menu scene that will not be discussed in this section as it does not incorporate any form of movement. The follow-scene required the implementation of a mechanism that allowed users to follow the trajectory of beta-2-agonist particles as they navigate the intricate network of airways within the lungs. On the other hand, the cross-section scene necessitated the implementation of a suitable movement system that enabled users to freely navigate and explore the scene at their own discretion.

4.11.1 Movement in the Follow Scene

During discussions with domain experts and stakeholders, it was determined that providing users with the sensation of travelling alongside medication particles was an essential feature of the application. This would be one of the differentiating features when comparing a VR application to traditional media and teaching methods. In these meetings, this type of system would often be compared to roller coasters, an area where VR has already been extensively explored. However, in contrast to roller coasters, the aim of the application was to provide users with the ability to freely control their speed, both forward and backward, to enhance the sense of agency and immersion in the VR experience.

The first iteration of this movement system was made with an approach focused on Unity's animation system. The XR rig, controlling the user's position, was carefully animated with keyframes, which define the values of attributes like position and rotation. In Unity, an animation is created by defining a sequence of keyframes. Each keyframe defines the position, rotation, and scale of the object at a specific moment during the animation. Unity then interpolates between the keyframes to create smooth and continuous motion. For example, if an object needs to move from point A to point B over a period of 5 seconds, keyframes would be set at both points, and Unity would interpolate the object's movement between those keyframes, creating a smooth motion from A to B over 5 seconds.

To streamline the animation process, Unity provides the option of automatic keyframe recording. When this option is enabled, selecting a specific point in time of the animation allows the user to position a GameObject precisely where desired. This action automatically creates a keyframe, which is added to the existing sequence of keyframes at the correct point. This process was used to create an animation that saw the XR Rig travel through the airways to an arbitrarily selected set of alveoli.

Users should have the capability to control their journey through the respiratory tract. In Unity, the speed of an animation can be linked to and managed by a variable. A float variable named "AnimationSpeed" was introduced and set to control the speed of the animated journey. To provide users with full control over the pace of their transit through the lungs, a slider was included in the application's wrist menu, allowing users to adjust a float value within a range of -2 to 2. Manipulating this slider altered the value of "AnimationSpeed," enabling users to regulate the speed of their journey. Users could traverse through the respiratory tract in a forward or backward direction and bring their movement to a complete stop at their discretion.

Facilitating the users' journey through the lungs by animating the XR Rig proved an adequate approach. However, it required a considerable amount of tedious work and, by extension, time to produce satisfactory results. This became especially apparent when adjustments in the size and position of the human 3D model had to be made. After these altercations were made, the path of the XR Rig's animated journey no longer aligned with the airways of the model. Using the original animation would result in the users clipping with various parts of the human model and going outside of the airways, as well as the start and end points would no longer be correct. There was not found a way to scale and reposition the trajectory defined in the original animation, effectively rendering all the work that went into creating it useless. Going forward with this approach would mean having to create a new animation following the new dimensions of the human model every time it is altered.

A new method was formulated to eliminate the risk of having to animate the XR Rig's transit through the lungs several times. The path system used for the breathing system was deemed appropriate once more. Rather than manually defining points which the XR Rig should move towards, the BPC provides an easy-to-use interface for creating and adjusting a path, allowing for quick iterations and adjustments. A path down into the lungs, illustrated by the green line in Figure 4.25, was created for the XR Rig to travel along. The process of defining the user's trajectory through the lungs by creating Bezier curves was found to be more efficient and accurate, resulting in an improved approach.

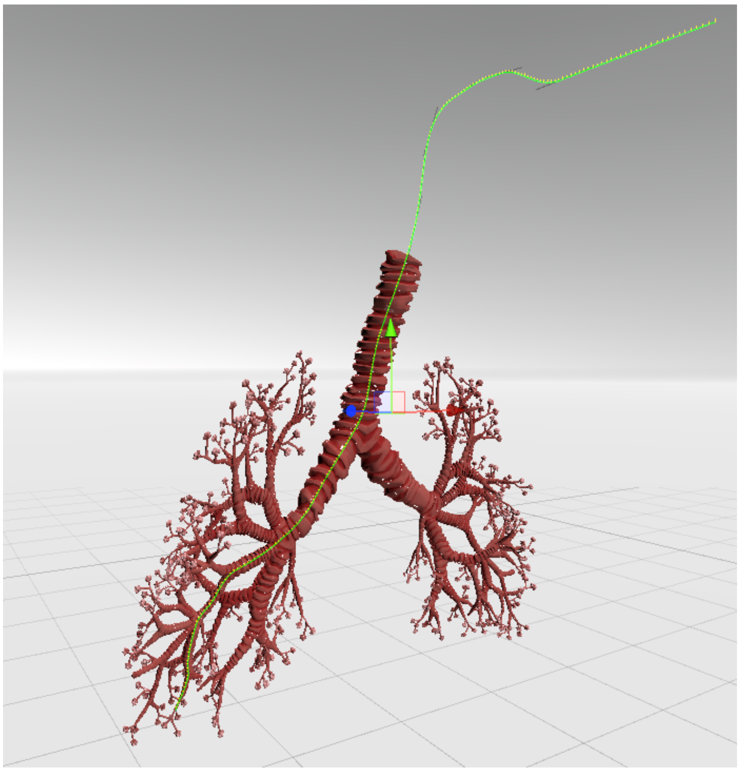


Figure 4.25: BPC Path for XR Rig going down into the lungs.

To implement this updated approach into the UI, modifications had to be made to the slider featured in the wrist menu to adjust the speed of the user's transit accordingly. Furthermore, each object designated to follow a BPC path necessitated the inclusion of a PathFollower script. The PathFollower script is responsible for defining the path to be followed and the code regulating the object's movement along that path. The script was slightly modified to enable the slider present in the wrist menu to control the ”speed” variable included in it.

During the development of the movement system for the "follow scene," a notable issue arose related to the maintenance of a constant speed. The issue arose due to a reduction in the size of the "tunnels" and an increase in the frequency of turns further down the respiratory tract. As a consequence, users' perceived speed would rapidly increase as they traveled along the path, leading to a potentially uncomfortable and nauseating experience towards the end of the journey. A speed that would initially be considered slow at the start of the respiratory tract would become unsuitable for comfortable navigation toward the end of the path. The users could manually reduce their speed to a more comfortable rate, however, the increase in speed was considered too difficult to control manually without causing discomfort. Additionally, having to continuously adjust their speed would take the users' focus away from the main aspects of the VR experience.

To address this issue, a solution was devised where the speed of the user's transit would automatically adjust according to how far along the path they had traveled, allowing for a more seamless and comfortable navigation experience. An algorithm was developed that calculated the relative distance traveled by a "PathFollower", and an appropriate speed reduction was calculated and applied by multiplying the speed variable with a reduction factor. This was done using the Mathf.Lerp [126] function, which returns a value that is a linear interpolation between the maximum speed and the minimum speed, based on the normalised distance traveled. Essentially, this means that the closer the object is to the end of the path, the slower it will move. The fastest travel speed that was deemed comfortable was found to be 2 at the start of the path and 0.2 at the end. Therefore, to simplify the calculation, the range of the slider in the wrist menu was set to -1 to 1, and the maximum speed and minimum speeds were set to 2 and 0.2, respectively. In practice, this means that if the slider is set to 0.5, the speed will be 0.5*2=1 at the start of the path and 0.5*0.2=0.1 at the end of it. As a result, the user experiences a deceleration of ten times the initial speed. However, due to the perceptual illusion of speed, the overall perceived speed remains relatively constant.

As mentioned in 4.8, the slider was later eliminated from the wrist menu, and an alternative method was adopted where users regulated their speed using the 'Grip' buttons located on the Meta Quest 2's hand controllers. These buttons support analog input, enabling users to adjust their speed by varying the pressure they apply. This approach alleviates the need for users to divert their attention to a specific menu area, as they can now effortlessly control their speed without taking their eyes off the pharmacological aspects of the application.

4.11.2 Movement in the Cross-Section Scene

The "cross-section scene" required a completely different approach to movement. Unlike the previous scene, this environment did not require the user to move synchronously with the medication, thus allowing for a more flexible system to be implemented. To promote user exploration and self-directed movement, a system was developed that enabled users to navigate the environment via the joystick on the right VR hand controller.

Included in the XR Interaction Toolkit, mentioned in 4.6, is a Locomotion System that facilitates a few different movement options for the XR Rig. Among these modes is one that allows for unrestricted movement along the x and z axes, creating a sensation akin to flight for the user. This mode was seen as an appropriate movement system for the "cross-section scene", and it was implemented relatively quickly. One limitation, however, was the absence of vertical movement along the y-axis. Given that such movement is essential for a comprehensive and free exploration of the lungs, it became necessary to develop a solution to this constraint.

To resolve this issue, a custom script was devised to enable the XR Rig to detect and respond to user input from the hand controllers, allowing the user to move along the z-axis. Considering that the current movement controls within the locomotion system necessitated that users place their thumb on the joystick, it was deemed appropriate to utilise the joystick's clicking feature as the user's input for controlling movement along the y-axis. The integration of these two movement systems provided users with the ability to navigate through the virtual environment along the horisontal plane by manipulating the joystick and along the vertical plane by clicking the joystick.

Through this approach, the absence of vertical movement was compensated for, and the user was able to navigate the lungs freely. However, the joysticks' click functionality only facilitated binary input. Consequently, while users were able to meticulously regulate their speed in the horisontal plane by adjusting the extent to which the joystick was pushed, they encountered a constant speed constraint when traversing along the y-axis. This constraint resulted in an inelegant user experience, impeding precise navigation to desired locations within the virtual setting. Consequently, following a similar strategy employed in the Follow Scene, the utilisation of the 'Grip' button on the hand controllers was reintroduced. In this instance, the 'Grip' button was repurposed to control vertical movement, as opposed to backward and forward progression along a predetermined path. Figure 4.26 depicts the in-application instructional interface designed to acquaint users with the movement controls employed within the scene.

Figure 4.26: Instructions for the movement controls in the Cross Section scene.

4.12 Simulating an Asthma Attack

In order to adequately represent the effects of asthma medication, it is necessary to first exhibit the symptoms of asthma. The presentation of the symptoms of asthma must precede the demonstration of their reduction via asthma medication.

Asthma simulation involves a complex interplay of three distinct components that work in tandem to accurately represent the condition. These include the animated contraction of the airways, as discussed in section 4.5, as well as the animation of mucus build-up and the modification of exhale audio, described in the previous section. To achieve a realistic simulation of an asthma attack when the user opts to activate one through the menu system, the synchronisation of the three key components is imperative.

The majority of the work related to the contraction of the airways was done in 3ds Max prior to the full-body model being imported into Unity. In this process, the mesh of the lung model was manipulated to animate the narrowing and opening of the airways, and these animations were subsequently baked into the model file when the model was exported in the FBX format. Within the Unity application, the animation is presented as an AnimationClip [127], which is controlled by an AnimationController [128], providing an organised framework for the animation of the lung model.

In order to achieve dynamic control over the animation of the full-body model in Unity, an AnimationController component is attached to the model in the visual editor. This allows for the selection and manipulation of specific AnimationClips through scripting, thereby enabling the linking of certain animations to UI elements, such as buttons within the tablet menu discussed in section 4.8. In this scenario, when the user selects the "Simulate asthma attack" option in the tablet menu, it initiates the main part of the asthma simulation, which is the animation of the narrowing of the airways.

In unison with the narrowing of the airways, an animation simulating mucus build-up inside the respiratory tract is played. Multiple techniques were experimented with to convincingly simulate mucus build-up within the respiratory tract.

One early idea included the use of liquid simulations. Attempts were made to use a free trial of an asset from the Unity store called Zibra Liquid [129] to facilitate real-time simulations of a thick, coloured fluid representing mucus. Zibra Liquid allows for the creation of visually convincing fluid simulations, with a range of parameters available for customisation, such as viscosity, surface tension, and turbulence.

This method produced mucus that was visually appealing in terms of its appearance. However, the manner in which the mucus interacted with the airway walls was deemed unsatisfactory. The default gravity settings included in the simulation caused the mucus to fall to the bottom of the airways, resulting in poor adherence to the walls. Various techniques were explored to overcome this issue, including adjusting fluid viscosity, manipulating simulation time, and gravity settings. Despite improvements in the appearance and texture of the mucus, achieving satisfactory results required more time than deemed reasonable. Moreover, continuing to use the Zibra Liquid asset would necessitate payment, and the high computational demands of the asset rendered it impractical. Consequently, this approach was abandoned.

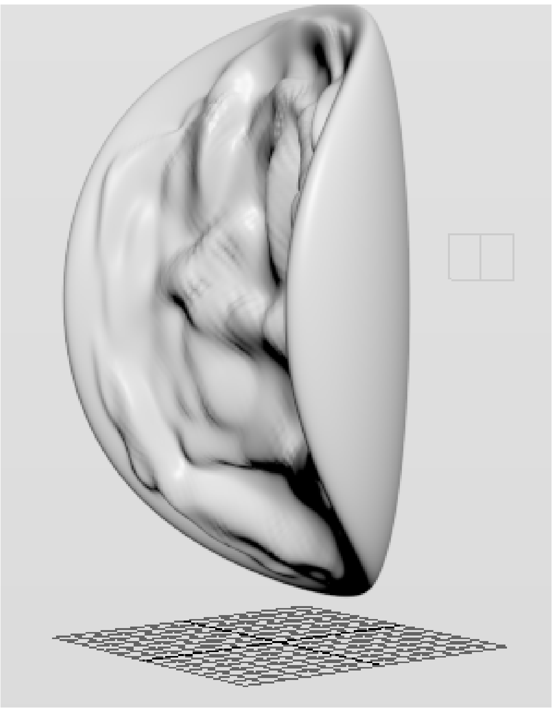


Figure 4.27: Blender mucus model

Another approach included the use of a technique where Shaders in Unity is used to give solid objects a liquid look. In contrast, a relatively straightforward and computationally cost-effective solution was ultimately implemented. Specifically, a customised 3D model created through Blender, an open-source 3D modeling software, was utilised. This involved flattening a sphere shape to form a disk, adding noise to create a textured surface, and subsequently curving the disk to conform to the shape of the airway tubes. This particular model is depicted in Figure 4.27. A number of copies of this model, varying in width, length, and size, were carefully rotated and positioned all around the outside of the tubes making up the airways, as shown in Figure 4.28.

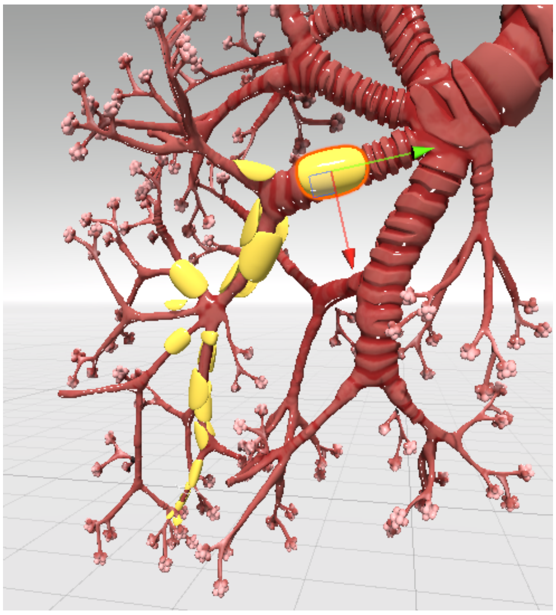


Figure 4.28: Mucus model placed around airways

The copies were then manually animated, using Unity's animation system, to gradually move inwards to intersect with the airways, thus creating the illusion of mucus secretion from the walls of the airways. The surface irregularities of the model, combined with the variable dimensions and width-to-height ratios, contributed to a natural and randomly distributed appearance of the simulated mucus.

When the user elects to simulate an asthma attack, all three of these components work together to create a realistic and immersive experience. The airway constriction causes breathing difficulties, and the mucus build-up makes it even harder to breathe. Furthermore, the sound effect of wheezing during exhalation further accentuates respiratory distress. This sets the stage for the presentation of the effectiveness of asthma medication in treating the condition.

4.13 Simulating the Effects of Asthma Medication

The visualisation of the transit of asthma medication through the human body was a crucial aspect of the VR application. The development of this visualisation was a complex process that involved collaboration between pharmacology experts and VR developers to ensure accuracy and realism. The asthma medication in question was the aforementioned beta-2-agonists, short-acting beat-agonists providing quick relief of asthma symptoms. While various administration methods, such as oral and intravenous, are available, the focus of the VR application was to simulate administration through inhalation.

4.13.1 Simulation in the Follow Scene

Similarly to the airflow simulation described in section 4.10, medication particles had to be depicted travelling down into the lungs. Manually animating the journey of medication particles through the airways using Unity's animation system was considered but deemed too extensive of a task. Therefore the BPC was once again a key component of the implementation. As the medication is inhaled, it travels along with the airflow, meaning that the previously constructed paths could be reused for the medication particles. However, one new path down into the stomach was created to showcase that not all the medication goes down into the lungs.

Initial iterations of visualising medication particles involved the implementation of multiple clusters of spheres, with each individual sphere representing a singular particle. Each cluster, composed of approximately 30 spheres, followed a distinct path. All the clusters originated from roughly the same point and diverged as they traversed further along their assigned paths, uniformly distributing throughout the lungs.

Two critical issues with this approach were identified. Firstly, the movement generated using this technique was deemed unnatural, and secondly, an enormous number of spheres and clusters were required to realistically depict the transit of asthma medication. While the clusters followed their designated paths, the spheres within each cluster remained stationary, resulting in a stiff appearance that did not accurately represent the turbulent nature of medication particle motion. The number of spheres needed to accurately depict the administration of asthma medication was significant. Using the approach would have resulted in a considerable amount of work in addition to a computational burden. This made it difficult to scale the visualisation, limiting its potential usefulness in a realistic educational setting.

To address these issues, a more sophisticated approach was developed that utilised particle-based simulation techniques to create a more realistic representation of the transit of the asthma medication. Unity's ParticleSystem [86], a robust tool that empowers developers to create dynamic and interactive particle-based effects within their applications, was employed. This tool facilitated the creation and customisation of individual particles, which could be controlled using a range of parameters such as size, colour, behaviour, and movement. With this approach, the simulation could accurately represent the chaotic motion of medication particles in the airways. The simulated medication particles exhibited apparent weightlessness, and an unintentional effect of their movement and lifetime was an apparent collision with the walls of the airways and subsequent disappearance, providing an illusion of absorption. The use of particle-based simulations not only enhanced the visual realism of the medication's flow but also streamlined the development process by enabling a more efficient workflow. As such, this technique proved to be an effective solution for the limitations of the previous approach. Figure 4.29 show the look of the medicine particles in their transit through the lungs.

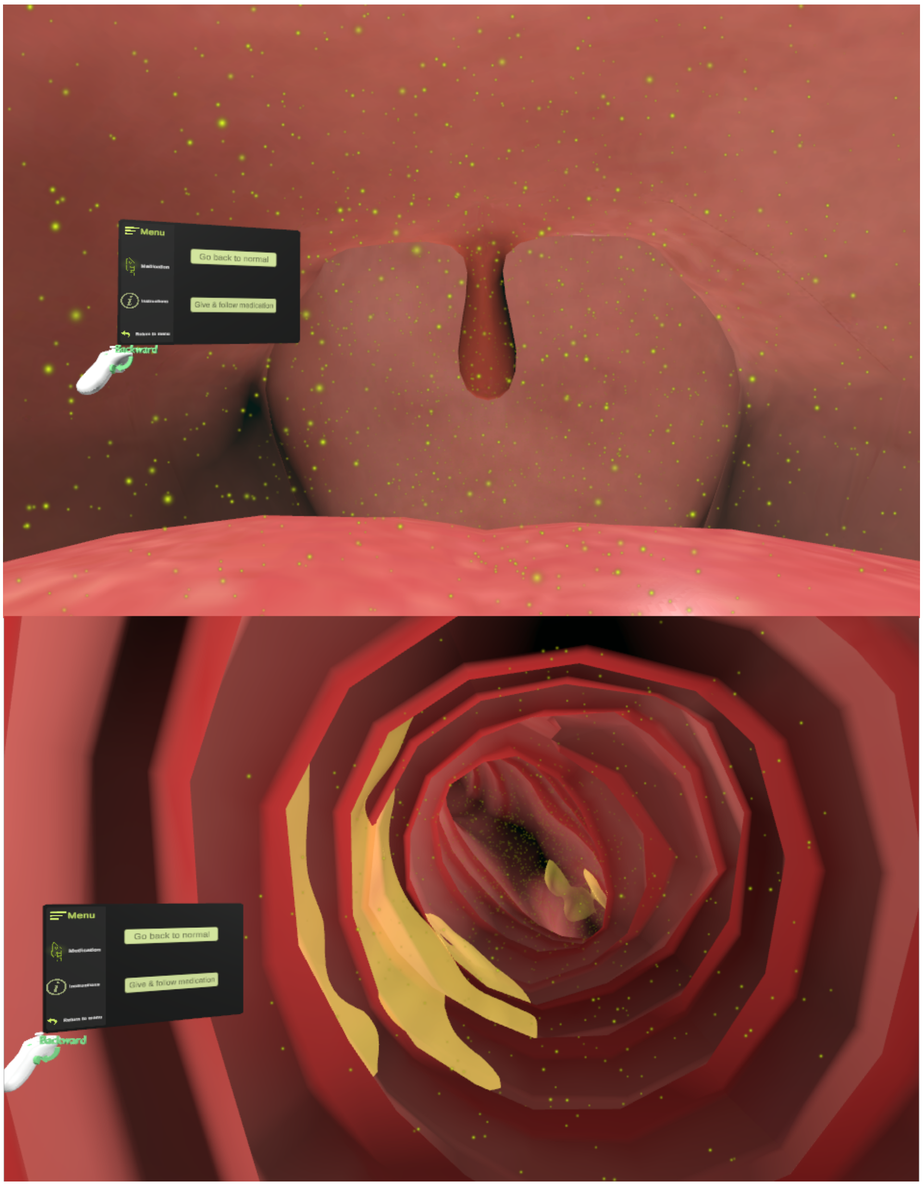


Figure 4.29: Medication particles, simulated with Unity's ParticleSystem, on their transit through the lungs.

The initial versions of the medication visualisation were decoupled from the respiratory system. In accordance with the average rate of respiration, the breathing system was set to simulate 12 breaths per minute. While the speed of the medication's transit was set independently at a pace, it could easily be observed and comfortably followed. Consequently, there was no synchronisation between the medication inhalation process and the accompanying inhalation sound and visualisation. In practical terms, the users would observe the gradual movement of the medication through the airways while concurrently hearing audio that alternated between inhalation and exhalation, along with corresponding respiratory visualisations. However, this approach did not accurately represent real-world events since the medication should ideally move along with the airflow during a single inhalation. Given that the application aims to simulate the administration of asthma medication through inhalation, this particular aspect was crucial to ensure accuracy in the simulation.

Two potential solutions were considered to address this issue. One possibility was to increase the speed of the medication particles so that they matched the pace of a typical inhalation. Alternatively, the speed of the inhalation could be decreased to match the comfortable pace set for the medication particles, and this approach could be seen as time slowing down to facilitate the observation of the medication. The latter approach was deemed more appropriate, as the speed required to keep up with the airflow of a typical inhalation was likely to be uncomfortable for users. Consequently, a new inhalation audio clip was produced, with a slower pace that matched the duration of the medication's transit.

To achieve this goal, the original inhalation audio clip was initially subjected to a stretching process. However, it quickly became apparent that merely stretching the audio clip would not suffice to produce a natural-sounding slow inhalation. Additionally, because the clip needed to be approximately 40 seconds long to match the transit time of the medication, it could quickly become irritating and uncomfortable to listen to. Therefore, adjustments were made to both the volume level and pitch of the stretched audio clip. The audio clip was modified to commence with a typical inhalation sound, and subsequently, the pitch was gradually lowered to simulate the effect of time deceleration, and the volume faded down. Towards the conclusion of the clip, as the medication approaches its destination, the pitch and volume are reverted to the standard level to produce a seamless progression into the subsequent normal exhalation. This approach achieved a somewhat natural-sounding slow inhalation and facilitated a smooth transition to the following exhalation.

Having developed the visualisation of the asthma medication's transit through the lungs, the simulated effects of said medication needed to be developed. Due to the previous development of asthma symptom simulation, a substantial foundation has already been established. As a result, certain effects employed in the asthma visualisation were readily adaptable for visualising the effects of the medication and could simply be reversed to show the impact of medication administration.

As detailed in section 4.5, the animation of the airway constriction and subsequent relaxation was created using 3ds Max. Upon importing the full-body model into Unity, these animations were included in the model and were, in essence, the inverse of each other. Thus, following the simulation of the symptoms of an asthma attack using the contraction animation, as described in section 4.12, the relaxation animation depicting the opening of the airways was employed to simulate the effects of the administered medication. The simulation of the effects of beta-2-agonists on asthma was, in large part, the reverse process of simulating the asthma attack symptoms. However, to achieve a more accurate representation of the medication's effects, the speed of the relaxation animation was set to a lower rate than the one of the contraction animation

[130].

To achieve an accurate simulation of the effects of the administered medication, it was necessary to further animate the mucus that had accumulated during the asthma attack. However, the low short-term impact of beta-2-agonists on mucus posed a challenge, as simply animating its disappearance would not suffice. The primary effects of beta-2-agonists in the treatment of asthma are to relax the smooth muscles that line the airways, which results in the widening of the air passages. It has little effect on the clearance of mucus[49]. As such, in order to ensure an accurate representation of the medication's effect, it was necessary for the mucus to remain during the expansion of the respiratory tract. The mucus needed to adhere to the walls of the airways and move with them as they expanded. This was essential to show that this particular medication mainly relieves asthma symptoms by counteracting the narrowing of the airways and has little effect on the mucus.

Creating an accurate simulation of the medication's effects required several steps. First, it was essential to create a visual representation of the mucus adhering to the interior walls of the airways. Next, this mucus needed to move in sync with the airways' expansion. Finally, the mucus had to dissipate gradually, completing the simulation. This process was carried out through a two-fold animation procedure. Initially, an animation was created where the 3D models, which were representative of the mucus, were meticulously manipulated to align with the movements of the respiratory tract's walls with regard to position, rotation, and size. Subsequently, the mucus was animated to show a gradual dissipation, ultimately disappearing entirely. The second animation was set to automatically start following the conclusion of the first. Figure 4.30 displays two screen captures captured from an identical viewpoint within the airways. The upper picture depicts the airways in a contracted state, including the accumulation of mucus. Conversely, the lower picture illustrates the aftermath of airway expansion, where the mucus adheres to the airway walls.

In order to comprehensively replicate the effects of beta-2-agonists, it was necessary to synchronise the animation portraying the dilation of the airways with the previously outlined animation of the mucus movement. Additionally, the breathing system was also incorporated into the simulation to ensure a realistic portrayal of the physiological changes. Specifically, the wheezing sound that characterizes asthma breathing, as described in section 4.12, was switched back to the representation of normal breathing as the airways open, allowing for increased airflow, thus further enhancing the authenticity of the simulation.

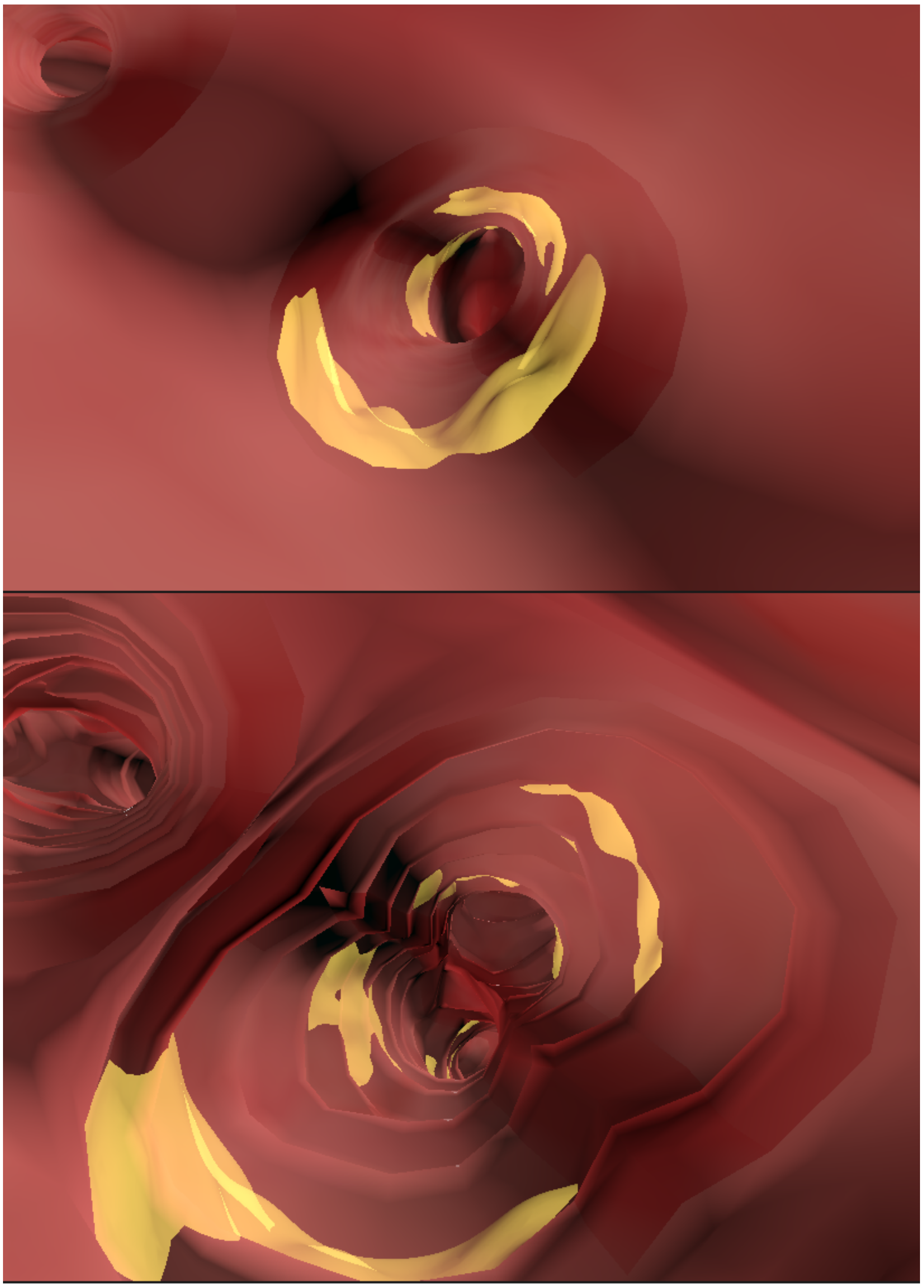


Figure 4.30: Medication particles, simulated with Unity's ParticleSystem, on their transit through the lungs.

Finally, the timing of the medicinal effects needed to be adjusted. Initially, the effects of the medications would initiate as soon as users would elect to administer the medication through the wrist menu. As soon as the medication particles started their transit through the lungs, the effects of the medication would be shown. This meant that the medication would be shown to take effect even before it had reached the site of action. To accurately represent the timing of the medication's effects, it was necessary to adjust the start of the animations so that the onset of action coincided with the arrival of medication particles at its target destination. This was accomplished through the use of a MedicationManager that monitored a designated ParticleSystem representing the medication and initiated the simulated effects of the medication once it reached the end of its path. This approach ensured that the timing of the medication's effects was accurately represented in the simulation.

4.13.2 Simulation in the Cross-Section Scene

The cross-section scene aims to provide users with a deeper understanding of how the medication works at a deeper level, highlighting the intricate processes involved in its therapeutic effect. In this section, we will focus on the visualisation process linked to the medication and the techniques used to achieve this.

Close cooperation with stakeholders and medical experts was essential to obtain a detailed description of the medication's behaviour and effects at the cellular level. The goal was to simulate the journey of the medicine through the bronchial tubes, as well as its diffusion across the airway epithelium layer, through the connective tissue, and finally reaching the muscle cells. This process ultimately results in the relief of the contraction in the bronchial tubes, as described in Chapter 4.5.

To simulate the general flow of drug molecules, we employed Unity's ParticleSystem, as used in the previous chapter. This approach allowed us to represent a larger number of particles flowing through the bronchial tubes without the need to animate each of them individually. However, to simulate a more accurate and detailed process of what happens to the medication, we needed to animate the path of each particle. For this purpose, we utilised Unity's animation system. The result was eight individual particles that moved through the bronchial tube, carefully adjusted in their paths to create a sense of them being drawn into the connective tissue before proceeding toward the muscle cells. Figure 4.31 shows how the two systems work in unison to simulate the transit of the medication.

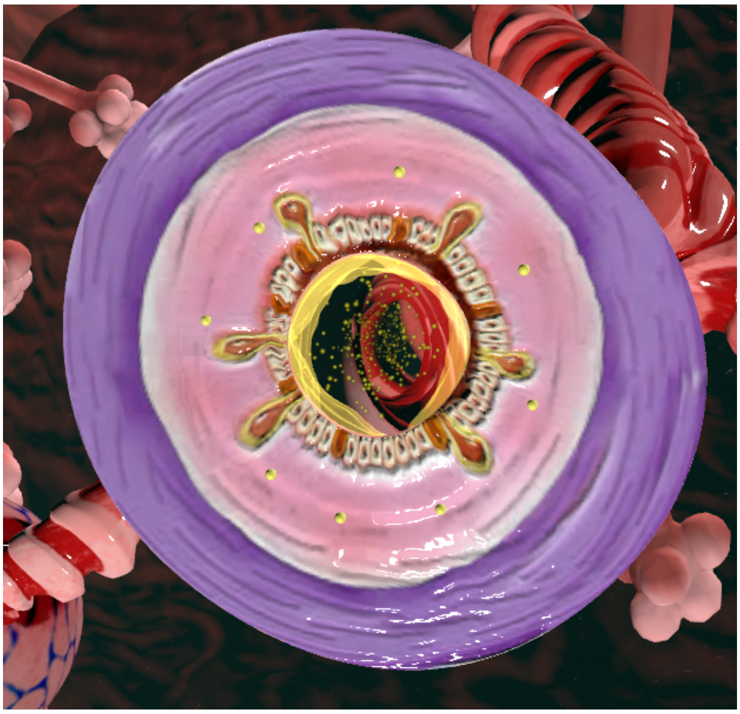


Figure 4.31: Medication particles simulated with Unity's ParticleSystem and manually animated.

4.14 Narration and Subtitles

To provide an additional layer of information and aid users with understanding the simulation, narrations explaining what was happening during the simulation were added. This allowed the user simultaneously observe the effects of the medication on the respiratory system and listen to a sound clip providing additional and more in-depth information. Subtitles were also included to cater to users who may have difficulty hearing the narration or who prefer to read the information. By providing both narration and subtitles, the VR application could cater to a wider range of users with different learning preferences and abilities. The composition of the narration script, as well as the subsequent recording process, were executed by our collaborating partners, Berg & Serkland. Afterward, the recording was further refined through post-processing in Audacity, where we applied techniques to eliminate stutters, long pauses, and extraneous noise from the audio. Additionally, a music layer was added to the recordings to enhance the listening experience and create a pleasant atmosphere for the users. To achieve this, a cheerful tune was selected from Epidemicsounds.com, which provides a vast library of royalty-free music that can be used in various creative projects. The selected music piece was then carefully blended with the narration using sound editing techniques, resulting in a harmonious audio experience for the users. The final output comprised six distinct audio clips that could be played in various sections of the application.

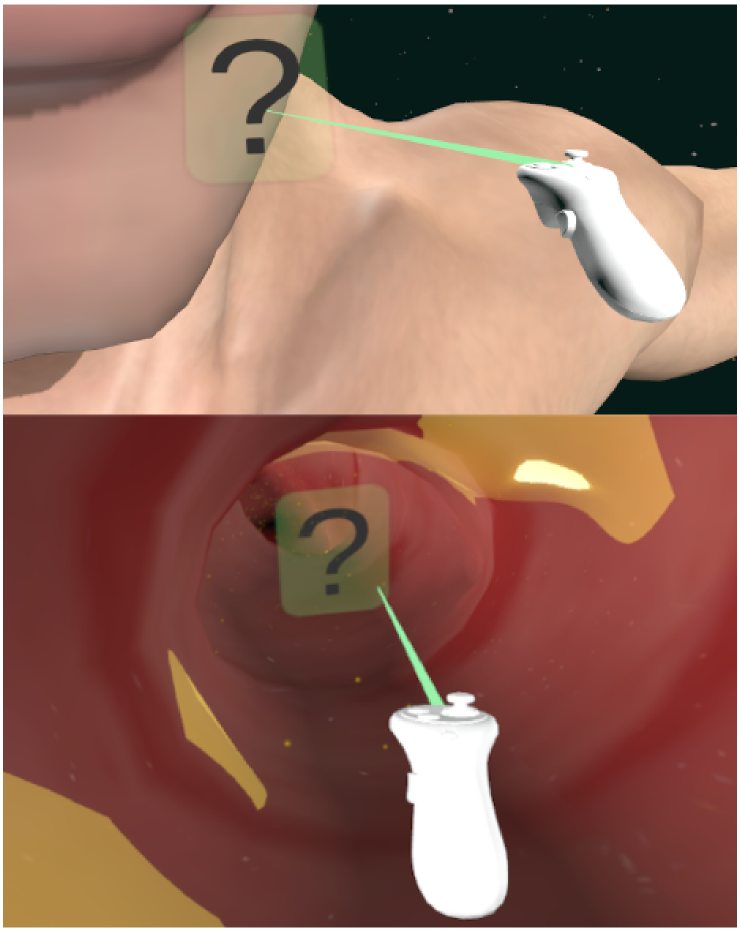
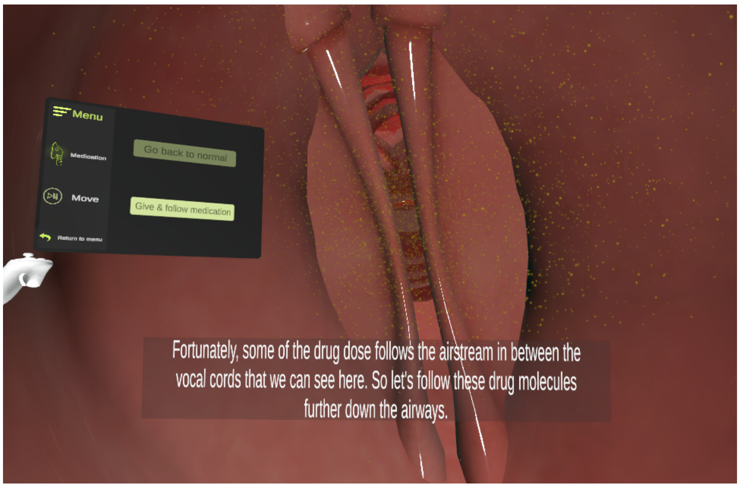


Figure 4.32: Interactable floating buttons used to activate narration

The VR application includes two methods for activating the audio clips. Some clips are triggered when the user interacts with floating buttons, shown in Figure 4.32, present in various locations of the application, whereas others are automatically played when the user selects a particular option from the wrist menu. The following scene comprises three interactable floating buttons that activate narration clips. One of these buttons is located just outside the mouth of the full-body model where the user's journey commences, while the other two are present inside the respiratory tract. The initial button activates a clip that serves to welcome the user and is the first to be encountered, while the other two buttons provide academic information regarding the journey and the effects of asthma medication.

The information given in the audio clips, which can be triggered inside the human model, is presented in such a way that it should be paired with the visual observation of the medication at a specific point of its transit. Consequently, although the application allows the user to freely travel through the respiratory tract independently of the asthma medication, the floating buttons within the



Fortunately, some of the drug dose follows the airstream in between the vocal cords that we can see here. So let's follow these drug molecules further down the airways.

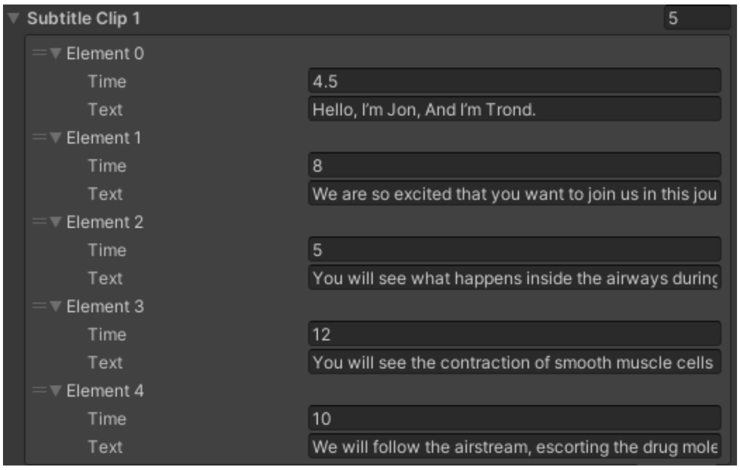
Figure 4.33: Narration & Subtitles activated in front of vocal folds.

respiratory tract are exclusively visible to the user when they have selected the "give & follow medication" option from the wrist menu.

This improved the cohesion of the information layers. However, there was still an issue that needed to be addressed. If a user had chosen the "give & follow medication" option, they would embark on a journey with a constant velocity on a path descending into the lungs. During the journey, just above the vocal folds, the area shown in Figure 4.33, users could activate an audio clip that provided information intended to be consumed at this specific location and time of the medication's consumption. The floating button was placed at this particular point; however, due to the constant pace of the journey, users would have already passed the location that the audio clip pertained to before the relevant information could be given. The user's speed could be adjusted manually by means of the slider found in the wrist menu, as previously discussed in section 4.11. However, altering the speed in this manner would cause the medication to move away from the user, as the slider does not affect the speed of the medication itself.

To address this issue, a temporary deceleration in the speed of both the medication and the user was activated in conjunction with the playback of the audio clip. Specifically, during the playback of the audio clip, the velocity of the medication and the user was reduced by a factor of 10. This deliberate reduction in speed facilitated the user's observation of the aspects referenced in the audio clip while maintaining synchronisation with the transit of the medication. Upon the conclusion of the audio playback, the velocity reverted back to its original value.

Ensuring synchronisation between audio and visual feedback was deemed crucial in some of the other audio clips. Consequently, the application was designed to remove the responsibility of timing the activation of a pharmacological simulation and an audio clip from the user. Instead, the audio clips are programmed to start playing automatically when the user chooses to commence a simulation



Subtitle Clip 1 5

Element 0
Time 4.5
Text Hello, I'm Jon, And I'm Trond.

Element 1
Time 8
Text We are so excited that you want to join us in this jou

Element 2
Time 5
Text You will see what happens inside the airways durinç

Element 3
Time 12
Text You will see the contraction of smooth muscle cells

Element 4
Time 10
Text We will follow the airstream, escorting the drug mole

Figure 4.34: Array of SubtitleText

from the wrist menu. This functionality is observable in the cross-section scene, where the user can simulate an asthma attack and, subsequently, the administration of asthma medication. Upon selecting either of these options from the wrist menu, a simulation is initiated along with an audio clip, ensuring that the simulated pharmacological aspects are occurring concurrently with the audio narration.

To enhance the comprehensibility of the narration and improve its accessibility to users who may experience difficulty in hearing, subtitles were incorporated. The language employed in the narrations could be considered complex, characterized by sophisticated terminology and abstract concepts, and subtitles were deemed a helpful tool to enhance the comprehensibility of the content for users.

To implement this in Unity, a struct, SubtitleText, was defined, which contains two variables: time and text. The time variable determines how long a subtitle should be displayed during the audio clip, while the text variable contains the actual subtitle text. Six arrays of SubtitleText's were created, one for each audio clip that required subtitles. Figure 4.34 show how the contents of the array were defined in Unity. When an audio clip is played, the corresponding array is iterated using a coroutine. The coroutine displays the first subtitle and then waits for the time specified in each subtitle line before updating the subtitle text with the next line. This process is repeated until all subtitle lines in the array have been displayed.

The display of subtitles to the user is facilitated through a basic UI element. This UI element takes the form of a panel with text and is attached to the XR Rig, which is then positioned at the bottom of the user's field of view. By employing this design, the subtitles are guaranteed to remain within the user's field of view, irrespective of any changes to the user's perspective. Figure 4.33 illustrates how the subtitles were displayed to the user.

4.15 Architecture

Unity uses an entity-component-based architecture to organise and manage GameObjects. Each GameObject is considered an entity in this architecture, and components are added to each entity to define its behaviour and appearance.

Components are reusable pieces of code that define a specific aspect of an entity's behaviour or appearance, such as its position, rotation, or movement. Entities can have multiple components attached to them, and the combination of components defines the overall behaviour and appearance of the entity.

One of the benefits of this architecture is that it allows for easy customisation and modification of entities. For example, if you want to add a new behaviour to an entity, you can simply add a new component that defines that behaviour, rather than having to modify the existing code.

Additionally, the entity-component-based architecture allows for better organisation and management of GameObjects, as each entity and its associated components are self-contained units that can be easily copied, moved, and reused throughout the game.

Apart from the built-in components provided by Unity, several custom components were developed to control the simulation's functionality. The implementation of the custom components involved scripting in C#, where each custom component represents a specific aspect of the application's logic. For example, one custom component, a **MedicationController**, was created to control the flow and behaviour of the medication in the simulation, while another component was developed to manage the various UI elements displayed to the user. Several of these custom controller components are attached to GameObjects within the scene, allowing them to interact with other components and objects in the game world.

By utilising this approach, the application's functionality can be broken down into smaller, more manageable pieces. Perhaps the most important components were the **AsthmaController** and the aforementioned **MedicationController**.

The AsthmaController script is responsible for controlling all the aspects that together make up the simulation of an acute asthma attack. It manages the state of the asthma attack, which can be toggled on and off by the user. The script takes in an **AudioController** that is responsible for switching the breathing sound to a wheezing asthma breathing sound during an asthma attack and back to normal afterward. Additionally, it uses a **MucusController** that controls the presence of GameObjects, representing the mucus that builds up during an asthma attack. Finally, the AsthmaController takes in an Animator that controls the animations showing the contraction and relaxation of the airways during the asthma attack and the healing process, respectively. The AsthmaController script acts as the central coordinator between these different components, providing the logic to tie everything together and create a seamless experience for the user.

Similarly, the MedicationController is tasked with coordinating various events that collectively form a simulation, specifically the medication administration process, as its name suggests. It includes several child objects with ParticleSys-

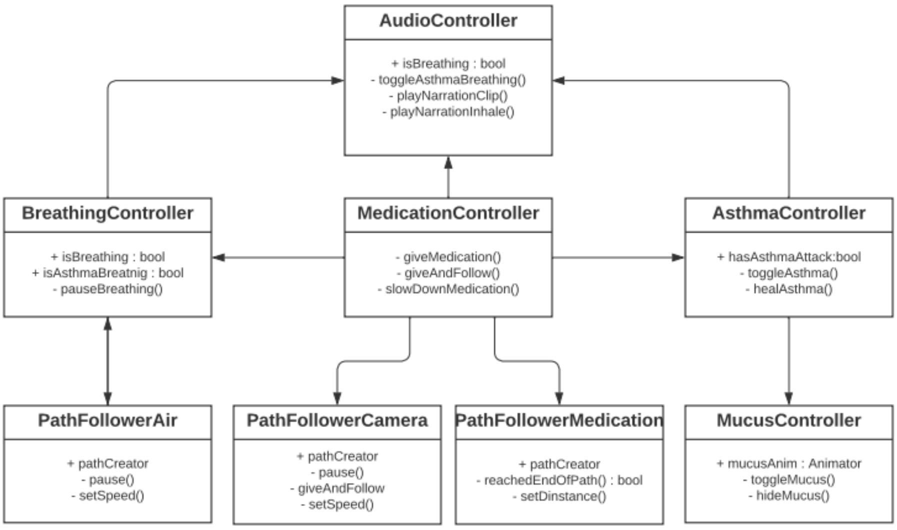


Figure 4.35: Diagram illustrating the most important controllers.

tem components provided by Unity, which are used to represent medication particles. The controller is responsible for controlling the emission rate and speed of these particles to simulate the flow of medication through the airways. It takes in a PathFollowerCamera, which controls the user's movement along the predefined path through the lungs in order for it to synchronise the journey of the user with the transit of the medication particles. This facilitates the "give and follow medication" functionality of the application. The MedicationController takes in both an AudioController and a BreathingController as parameters. The AudioController is used to initiate the playback of a special inhalation sound clip during medication inhalation, while the BreathingController is utilised to pause the normal loop of inhales and exhales during the special inhalation clip playback. Finally, the MedicationController takes in an AsthmaController, which is responsible for initiating the healing process once the medication particles reach the affected areas. Overall, the MedicationController plays a critical role in guiding the user through the medication administration process, making it an essential part of the interactive simulation.

Figure 4.35 show a high level overview of how the main controllers are interconnected to provide the logic of the application.

4.16 Optimisation and Performance

Optimisation and performance are key components of any virtual reality application that aim to give users a seamless and engaging experience. There are two main approaches to running a VR application, each suitable for various VR platforms. These can be either PC-tethered or standalone.

PC-tethered VR systems are configurations that require a connection to a powerful computer via a cable or wireless connection. These configurations rely on the computer's hardware and processing power to render high-quality graphics and handle complex simulations. Standalone applications, on the other hand, run directly on the VR headset without any connection to an external source. Throughout the development and during the evaluation sessions, the application primarily operated using a PC-tethered system. However, we also made attempts to improve the performance of the standalone version.

One of the most significant performance issues we encountered was the time delay experienced when switching between the main scenes. This was mainly due to the heavy load of processing the complex 3D models. In order to address this issue, it was necessary to find a balance between the visual fidelity of the models and the overall performance of the application. One of the initial steps taken was to reduce the polygon count in the 3D models. This was achieved by experimenting with different smoothing values in the **Meshsmooth** component inside 3ds Max, as discussed in section 4.4. By doing so, we significantly reduced the amount of time required for navigating between the different scenes. This optimisation was beneficial not only for the PC-tethered version but also for the standalone application, as both versions require efficient resource management to deliver a smooth user experience.

Another issue we faced was related to delays and low frame rates while following the journey of the medication. This not only affected the user's experience traversing through the airways but also impeded the use of the wrist menu, as it resulted in lagging and difficulty in pointing and interacting with it. In the earlier versions of the application, the 3D model used in the follow-scene included all of the inner components and organs that were originally part of the model. This had a significant impact on the simulation quality when navigating down the airways, as it resulted in lagging and low frame rates, particularly in the standalone application.

Initially, attempts were made to rectify this issue by adjusting various settings related to the models in Unity, such as disabling shadows and reducing texture quality. However, these adjustments provided minimal improvements. Consequently, a more impact solution was employed, which involved the removal of all unnecessary components from the model that was not essential to the simulation or related to the lungs. This approach produced a greater result, leading to smoother movements and a more responsive wrist menu.

Chapter 5

Results

To gather feedback and enhance the application accordingly, we conducted two rounds of user evaluation sessions. This chapter presents the outcomes of both sets of evaluation sessions, including the enhancements implemented between the two sessions. Additionally, we provide an overview of the overall results from various perspectives.

5.1 The First User Evaluation Session

The first round of sessions took place on March 29, 2023, at HUH. Four external participated in the evaluation, providing feedback on the VR application through a System Usability Scale and a survey related to the use of VR in pharmacology. The participants also provided verbal feedback throughout the session. Two of the participants were specialist candidates medical doctors who have completed their medical education and are currently undergoing specialised training in a specific area of medicine. The other two test subjects were medical students enrolled in the medical degree program at the UiB.

As none of the test subjects had ever tried VR before, they were given a short introduction to the basics of VR. Then a more specific walkthrough of the pharmacology application they were about to try that included images from the application and some text explaining various parts of the pharmacology application's interface and functionality.

One by one the participant got to try the application whilst their interactions with the virtual environment were being observed and recorded. The tester got to explore the environment, menus and features freely but were guided in the right direction if anything was unclear or there were features they had not tried yet.

Overall the verbal feedback from the evaluation session was very positive, all the users seemed to like the experience and everyone could see how the product could provide value in their field. Everyone managed to navigate the UI, however, we did observe that sometimes there were too many options. The menu system could benefit from having some buttons removed or potentially combined in order for the user to more efficiently see the desired outcome. While options can provide flexibility and customisation, an excess of choices in a UI can potentially result in confusion and unintended use.

Participants expressed that viewing pharmacology in VR offers a completely different and more engaging experience compared to traditional 2D methods, and that you have to try it to understand. One tester noted that they sometimes have trouble understanding where things are in relation to each other and that a VR application could help with that.

Upon the completion of the application testing, the participants were asked to answer a survey conducted through Google Forms. The survey consisted of the widely recognised System Usability Scale (SUS), as well as a custom questionnaire designed specifically for this study. As mentioned earlier the SUS is a recognised tool for evaluating the usability of artifacts.

After the first four participants had answered the questionnaire, the average SUS score was calculated to be 82.5. Bangor et al. [112] have proposed a threshold of 70 as the minimum score for considering an artifact as passable, with better products scoring in the high 70s and upper 80s. A score of 82.5 puts the application somewhere between good and excellent on the adjective rating scale proposed by Bangor et al.[112] which can be seen in Figure 5.1.

Statement four of the SUS, "I think that I would need the support of a technical person to be able to use the VR application", received the most mixed responses from the participants. Two participants agreed with the statement, indicating they believed technical assistance would be necessary for them to use the application. One tester reported disagreement and one reported strong disagreement, both expressing more confidence about being able to use application on their own. There might be some confusion connected to this statement, however. Participants could struggle with the question of whether they should consider the overall system or just the application itself. Considering the test setup that was used, participants could have envisioned more work being necessary than what was actually the case. This uncertainty can make it challenging for participants to provide accurate and actionable feedback, as it requires them to consider both the application and its surrounding system.

It may be tempting to dive deeper into the answers of each individual question, however, Brook [111] notes that the scores for individual items are not meaningful on their own. This is reiterated by Bangor et al. [112] because of their results that indicate a significant correlation between all the statements. One should instead only report the overall SUS score. While a single number cannot convey the full picture of our application's usability, it provides an easy-to-understand indication that everyone can understand. Given the low number of participants one should not put too much emphasis on this number, however, it can indicate that the UI does not detract from the main goal of the application which is to show pharmacological concepts.

As part of the testing process, our custom questionnaire was administered to the participants to gauge their perception of how VR when applied to pharmacology. Similarly to a SUS the custom questionnaire included alternating positively and negatively phrased statements. The results from the questionnaire revealed that

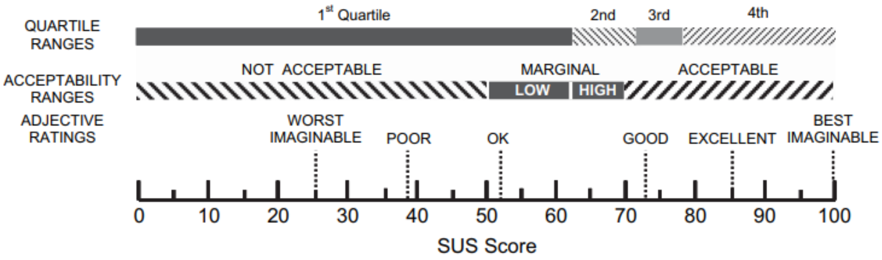


Figure 5.1: A comparison of mean SUS scores by quartile, adjective ratings, and the acceptability of the overall SUS score. Figure from Bangor et al. [112].

the participants where mostly in agreement. More so than the results from the SUS, where the answers where a bit more diverse.

All four participants indicated strong agreement to the statement "Using a VR application in pharmacology education can make learning more engaging and interactive." and strong disagreement to "A VR appliaction does not provide any meaningful benefits compared to traditional teaching methods such as books, lectures, and videos." These responses suggest that the participants perceive VR as a valuable tool in pharmacology education, with the potential to enhance engagement and interactivity. Additionally, their disagreement with the statement that VR lacks meaningful benefits compared to traditional methods indicates that they see value in incorporating VR into pharmacology education, perhaps as a complementary approach to existing teaching methods.

The participants also indicated that they believe that a VR application can help students visualise and understand pharmacological concepts more easily, with three of them reporting that they agree with the third statement of the custom questionnaire and one participant reporting strong agreement. They were also in agreement that VR can improve students' motivation to learn and provide a more immersive and memorable learning experience. In all cases, participants reported either disagreement or strong disagreement to statements indicating that the use of VR in pharmacology education adds unnecessary complexity and that it takes away from the learning experience.

The answers for statement eight, "The benefits of using a VR application in my field of study does not outweigh the challenges and limitations", where the most varied. Two participants reported disagreement, one reported strong disagreement and one reported neither disagreement nor agreement. A weakness of this statement is that the participants might not know what the possible challenges and limitations are. It is likely that they have not been exposed to the full range of difficulties associated with VR given that non of them had tried VR before, and answered based on perceived drawbacks. Further research could explore the specific challenges and limitations that users perceive in using VR in pharmacology education, and how these perceptions may impact their overall perception of the benefits of VR in their field of study. Understanding users' perspectives on challenges and limitations can provide valuable insights for improving the design and implementation of VR applications in pharmacology education to address potential concerns and enhance its effectiveness as an educational tool.

Overall the custom questionnaire results indicate that the participants are positive to the implementation of VR into pharmacology education. The results lead us to believe that both students and professionals are open to the idea of incorporating VR technology into pharmacology education, either in addition to, or in some cases, instead of traditional teaching methods.

5.2 The Second User Evaluation Session

The following user evaluation was conducted at HVL, building upon the insights gathered during the first round of sessions. This time, we expanded the scope of the test group to include both students and educators in order to gather a broader range of perspectives on the VR application. To obtain more reliable results, we also increased the number of participants, following the recommendation by Knudsen [131], which suggests that a minimum of 8-12 test persons is required for reliable findings. A total of five educators and four first-year nursing students participated in this session.

The evaluation session followed a similar procedure to the first one, with participants receiving a brief introduction to the basics of VR and a more specific walkthrough of the application. Each participant was provided with the opportunity to explore the application as we carefully watched their interactions within the virtual environment. This time, we also used screen recordings of each individual session to capture the user's interactions in real-time. These recordings provided valuable data for later analysis, enabling us to study how the different parts of the application were perceived and to identify any challenges or difficulties they encountered.

In response to the feedback received from the first session, several changes were implemented to improve the application's usability and user experience. One of the issues users faced was navigating between the functionalities due to the complexity of the wrist menu. This included users getting stuck or unsure how to navigate further in the application. Additionally, sometimes functionality gets missed or overlooked due to an overwhelming number of choices to explore. To address this problem, we simplified the menu by reducing and combining the available options for the user, aiming to create a more intuitive and seamless experience. As another step towards improving the menu's clarity, the number of side menus was decreased, and the icons were changed with more meaningful representations to make it easier for users to grasp their intended function.

In the second user evaluation, we introduced a new feature aimed at enhancing the learning experience and providing users with valuable information as they navigate through the airways and explore the lungs. With the support of our stakeholders, we incorporated multiple audio clips into the application, which were recorded by medical experts in the field. The content of the audio primarily focused on asthma and its effects on the airways, including the action of the medication and the physiological changes occurring during an asthma attack. These audio clips were integrated into the virtual environment, with buttons placed in specific locations throughout the scene that users could interact with to access the relevant information. In addition, we also implemented subtitles that appeared on the screen whenever an audio clip was playing.

As with the first evaluation session, the verbal feedback collected during this session was predominantly positive. Both students and teachers expressed enthusiasm about the application's potential value in the field of pharmacology education. The participants were able to navigate the UI effectively, although a few who had never used VR before initially experienced difficulties using the controllers to interact with the menu.

Upon completion of the application testing, participants were asked to complete the same survey as in the first session, which included the SUS and the custom questionnaire tailored to the study. An additional question was added to the questionnaire to identify the participant's roles as either students or teachers.

After analyzing the responses from the participants, the average SUS score was calculated to be 80.55, which is slightly lower than the score achieved in the first session. The slight reduction could be due to several factors. Importantly, the number of participants in the second evaluation was higher, which could lead to a broader range of responses. Another factor that might have influenced the SUS score is the inclusion of both students and educators. It is conceivable that teachers might have had different expectations or requirements from the VR application than students, leading to a broader spectrum of usability assessments. Despite this, it is important to note that a score above 80 is still considered good, indicating that the application was generally well-received by the users.

There was a more diverse range of prior experience with VR compared to the first session, where none of the participants had tried VR before. This time, three of the participants reported that they had never used VR, four stated they had tried VR 2-5 times, and two participant had used VR more than five times.

Regarding the third question of the SUS, "I thought the VR application was easy to use", the responses leaned towards the positive side. Three strongly agreed with the statement, while two participants agreed and four reported "neither agree nor disagree". This suggests that a considerable number of the participants found the VR application user-friendly and easy to navigate, regardless of their prior experience with VR. However, the neutral response from one participant indicates that there may be room for improvement in the application's usability.

Considering the custom questionnaire, the positive sentiment towards using VR in pharmacology education remained strong. Of the nine participants, eight strongly agreed with the statement "Using a VR application in pharmacology education can make learning more engaging and interactive", while one agreed. Moreover, for the statement "A VR application does not provide any meaningful benefits compared to traditional teaching methods such as books, lectures, and videos", the majority strongly disagreed, and two participants stated they disagreed. These findings agree with the first session's results and indicate a common perception among students and educators about the benefits of incorporating VR into pharmacology education.

The participants provided several suggestions for improvements and new features in learning pharmacology using the VR application. One participant expressed interest in delving deeper into the physiological response of complex pharmacology, such as exploring the cellular level in greater detail. Although the current application already covers beta-2-agonist treatment at a cellular level, it is apparent that a much more detailed 3D-model is needed to allow users to closely examine the cells and their interactions. The potential to combine the pharmacology component with anatomy was also mentioned by a participant, as they found it particularly interesting from a VR perspective. This feedback highlights an opportunity for further development of the application, which can provide users with a more in-depth understanding of complex pharmacological processes.

Another recommendation was the incorporation of multiple-choice questions to test and reinforce learning. This addition could provide an interactive assessment method that further engages users with the material. Additionally, two teachers suggested during the test that more information in the form of text could be very useful to explain the different parts observed in the lungs, particularly the various sections of the bronchial tubes.

Overall, the second user evaluation reinforced the positive feedback gathered during the first session, with participants expressing a strong belief in the potential benefits of incorporating VR into pharmacology education. As both students and teachers were involved in this evaluation, the results provide a more comprehensive understanding of the perceived value of the VR application across different user groups. This feedback, along with the results from the first user evaluation, offers valuable insights for further development and improvement of the application, ensuring its effectiveness as an educational tool in the field of pharmacology.

Chapter 6

Discussion

This chapter builds upon the findings from the previous chapter, discussing the results in greater detail. The chapter also considers opportunities for future research and development in the use of VR in Pharmacology education.

6.1 Summary of Findings

In the two rounds of user evaluation sessions feedback was gathered to understand the application's strengths and areas of improvement. The results of the evaluation revealed that the application achieved an average SUS score of 82.5 in the first session and 80.55 in the second session, placing it between good and excellent on Bangor et al.'s scale [112].

During the initial evaluation session, four external participants without prior experience in VR technology engaged with the application. While all participants found the application navigable, concerns were raised regarding its complexity due to an excessive number of options. In response to this feedback, adjustments were made, such as simplifying the menu system and improving the movement controls.

In the second round of evaluation sessions, a total of nine participants, consisting of both first-year nursing students and teachers from HVL, participated. The feedback was generally positive, recognising the potential of VR as a tool for enhancing pharmacology education. Some of the suggestions for improvement included visualisation of complex processes occurring at the cellular level, combining pharmacology with anatomy, and the inclusion of multiple-choice questions for testing and reinforcing learning.

The complexity of the wrist menu was a recurring theme in the feedback from both sessions, both on the questionnaire responses and during verbal exchanges during the testing phase. Users noted that they sometimes felt overwhelmed by the number of options available, which led to confusion.

To address this issue, specific menu options were eliminated, while others were consolidated. Notably, the merging of medication administration and subsequent tracking of its transit as into a single button significantly mitigated the complexity associated with navigation and interaction within the application. This improvement facilitated a shift of user attention towards the displayed content, rather than being impeded by functional complexities. The participants appreciated the innovative and interactive nature of the application, which brought pharmacological concepts to life in a way that traditional methods could not.

In the context of RQ2, the custom questionnaire administered during the evaluation sessions provided valuable insights into the perception of the VR application. Across both sessions, a substantial majority agreed or strongly agreed that using a VR application in pharmacology education can make learning more engaging and interactive. Similarly, when asked whether VR could help visualize and understand complex pharmacological concepts more easily, the majority responded with either strong agreement or agreement. These responses underscore the potential value and effectiveness of VR as a learning tool in pharmacology education.

In summary, the results from both evaluation sessions indicate a positive reception of the application, with users appreciating its potential to enhance engagement and interactivity in pharmacology education. Despite minor usability issues, the application scored well on the SUS, demonstrating its overall user-friendliness and potential as an educational tool. The results suggests that an engaging and informative VR application has been successfully developed.

6.2 Key Findings from the Development Process

The promising results observed in medical education across multiple disciplines have spurred questions about the applicability of VR technology in pharmacology education. To address some of these questions, we embarked on the development of an application through DSR that could serve as a platform for research into this matter.

Our objective was to contribute new knowledge to the existing knowledge base and to advance the understanding of the potential benefits and limitations of this technology in relation to pharmacology education. Specifically, we aimed to answer the question, "How can we design a Virtual Reality simulation that enables users to observe the pharmacological effects of beta-2-agonists in the treatment of asthma?".

This section aims to provide a review of the key findings from the development process and highlight their relevance in addressing RQ1 [1.2]. The subsequent discussion will delve into the implications of these findings and shed light on their potential contributions to the field.

In accordance with the principles of DSR, the development process itself was to be considered research. In the initial phases of the project, the scope of the application was limited to the treatment of asthma attacks. This decision was based on a variety of factors, including the feasibility of achieving the project objectives within the allotted time frame, as well as the desire to effectively demonstrate the potential of virtual reality technology in this context. As such, we formulated RQ1 [1.2]. This research question served as a guide throughout the development process, ensuring that all design decisions and iterations were aimed at answering it.

The research project yielded several noteworthy insights and findings. The choice of utilising the Unity game engine provided certain advantages. The UI of the application underwent multiple iterations to ensure ease of use, with a focus on drawing attention to the educational aspects and minimising complexity. Streamlining the UI design and simplifying user choices were key considerations.

Additionally, the project recognised the significance of employing tools and techniques to simplify the development process and enhance workflow efficiency. In the later stages of development, the application derived from the research project underwent evaluation through two distinct user evaluation sessions, wherein quantitative assessments were employed. The first session yielded an overall SUS score of 82.5, while the subsequent session resulted in a slightly lower SUS score of 80.55.

The choice of Game Engine alluded to above ultimately fell on Unity for this project. Throughout the development period, it demonstrated good performance and flexibility in implementing various features and functionalities required for the simulation. Additionally, the availability of numerous libraries and plugins, as well as a well-established community with a plethora of resources such as online documentation, forums, and YouTube videos, provided ample support for the development process. These factors, combined with Unity's compatibility with various hardware systems, made it a practical choice for the creation of a simulation of pharmacological effects in the treatment of asthma.

The UI of the application was a crucial element that underwent several iterations during the development process. In any software system, the UI plays a significant role in the user's experience. However, in novel media such as VR, the unfamiliarity with the technology can amplify the perceived complexity of the UI. Consequently, the importance of the UI can become even more pronounced in the context of VR applications. Therefore, it is crucial to carefully design and simplify the UI to ensure ease of use for the intended user group. Additionally, when designing an application intended for educational purposes, the primary focus should be on achieving the intended learning outcomes. As such, it is important to ensure that the UI does not detract from the intended educational experience and does not require an excessive amount of time to become familiar with it.

As described in section 4.8, the UI and wrist-mounted menu, in particular, went through several iterations. Notably, a recurring theme across these iterations was the pursuit of improvement through the means of simplification. This area of improvement was identified through verbal exchanges as well as observed from the screen recordings of the users' interactions from the second evaluation session. Various design refinements were undertaken to streamline the UI, enhancing its usability and reducing the number of choices users had to make to get the experience that we had intended. Freedom of choice can be a good thing. However, it is imperative to ensure that such freedom does not compromise the primary focus and objectives of the application.

In addition to the aforementioned emphasis on simplification within the UI design, the project also recognised the importance of identifying and utilising various tools and techniques that facilitated the simplification of the development process itself, thereby fostering a more streamlined workflow.

Two distinct tools have demonstrated their instrumental role in efficiently reducing the workload and concurrently elevating the overall quality of the application. In particular, the application's visual representation of medication was significantly enhanced by leveraging Unity's ParticleSystem and the BPC sourced from the Unity Asset Store. The utilisation of the BPC extended to the design of both the player movement system and the breathing visualisation in the application. These tools effectively facilitated the adoption of more streamlined techniques, thereby culminating in advancement in the medication visualisation process.

In order to assess the usability of the application, we conducted two user evaluation sessions. These evaluation sessions involved quantitative assessments, specifically employing the SUS to gauge usability. The initial session resulted in an overall SUS score of 82.5, indicating a high level of user satisfaction with the application. Subsequently, in the following evaluation session, the application achieved a slightly lower SUS score of 80.55, which still demonstrated a favorable user perception of the application's usability.

The scores from both evaluation sessions would put the usability of the application between good and excellent on Bangor et al.'s [112] scale. These scores indicate that the users found the application to be user-friendly and effective in fulfilling its intended purpose, thereby validating the efforts put into its development and design.

It is worth noting that the first session included a relatively small participant group of only four individuals, which may raise concerns regarding the generalizability of the results. However, these concerns were addressed in the subsequent evaluation session, which involved a larger participant group of nine individuals.

Given the relatively small number of participants in the first session, caution should be exercised in drawing definitive conclusions from the observed difference in SUS scores between the two evaluation sessions. Furthermore, it is noteworthy that the difference in scores amounted to only 1.95, which could be considered within the expected margin of error. Therefore, it would be inappropriate to speculate whether the observed difference in scores can be attributed solely to the changes implemented in the application between the evaluation sessions.

To obtain a more robust assessment of the application's usability, the results from both evaluation sessions can be considered collectively. The two versions of the application exhibited relatively similar characteristics, and when the responses from both evaluation sessions were combined, the overall sample size increased to 13 participants. This larger sample size enhances the statistical robustness of the study and strengthens the generalizability of the findings. The average SUS score across the two sessions was calculated to be 81.525, giving a more rigorous measure of usability. This approach mitigates some of the potential limitations associated with the first session's smaller participant group.

The design presented in Chapter 4 outlines an approach to address the research question posed in this thesis. However, it is imperative to acknowledge that this study does not claim that the described methodology is the optimal or the only way of addressing the research inquiry. The development of an application for this specific use case involves a multitude of options that must be considered and chosen, ranging from minor design choices, such as the colour of a button in the UI, to more consequential decisions, such as the selection of a game engine. Therefore, it is important to recognise that the presented methodology is only one possible approach and that other valid approaches may exist.

One potential weakness of the SUS is its reliance on users' retrospective memory. It is possible that users might focus more on their most recent experiences with the system and base their responses primarily on those experiences. This can lead to a bias where users' evaluations are influenced by the final interactions or moments with the system rather than considering the entire user experience.

An aspect that remained untested in the evaluation of the application pertains to the potential occurrence of simulator sickness, which is a recognised weakness associated with VR experiences. The occurrence of simulator sickness could potentially undermine the overall usefulness of the application if users were to experience discomfort or adverse effects.

The limited duration of participants' engagement with the application, which lasted under 10 minutes during the user evaluations, prevented a thorough examination of this aspect. While none of the participants reported feeling sick, it should be noted that they were not specifically asked about symptoms of simulator sickness. As such, the absence of reported sickness experiences should not be interpreted as evidence regarding the potential presence or absence of simulator sickness resulting from the use of the application.

The decision not to test this aspect during the evaluations was made to prioritise the assessment of the application's usability. Nonetheless, it remains important to acknowledge the potential influence of simulator sickness and recognise the need for further investigation, potentially involving longer exposure times to accurately evaluate its impact on users' experience.

Based on the insights and findings of the research project, some key recommendations can be made. Unity has demonstrated good performance and flexibility for simulating medicinal effects in a virtual environment. Its compatibility with various hardware systems, availability of libraries and plugins, and strong community support make it a practical choice. Additionally, when developing educational applications, particularly in novel media such as VR, careful attention should be given to the UI design with an emphasis on simplicity.

Tools such as Unity's ParticleSystem and the BPC from the Unity Asset Store yielded significant improvements in both the visual representation of medication and its development process. Given the notable benefits experienced in the application's development, both tools warrant careful consideration for future expansion efforts involving a broader range of medications.

Further research in the field could explore alternative methodologies for addressing the research question and developing similar applications. Different design choices could be investigated to determine their impact on user engagement and learning outcomes.

Additionally, conducting studies with a larger sample size to improve the validity and generalizability of the findings would be beneficial. Extended durations of exposure could be employed to assess the occurrence and impact of simulator sickness, providing valuable insights into the potential challenges and limitations of VR applications in an educational environment.

By adhering to the principles of Design Science and aligning all design decisions and iterations with the objective of addressing RQ1, the development of the VR application has yielded notable findings. These findings include the enhancement of the UI through simplification and the recognition of the significant role played by the utilisation of pre-existing tools in improving both the workflow and the overall outcome of the application. Based on the comprehensive description of the development process presented in section 4 and further analysis in this section, it can be asserted that the description provided therein serves as a substantial response to RQ1 [1.2].

6.3 Perceived Effectiveness of VR in Pharmacology Education

Building upon the VR application's design and implementation, our project explored its effectiveness as an educational tool compared to traditional methods, as perceived by students and educators. As per the DSR process, in addition to the development process providing new knowledge, the developed artifact should be evaluated in the context of its intended environment. This led to our second research question: "How do students perceive the effectiveness of VR applications in helping them learn pharmacology concepts compared to traditional teaching methods such as lectures, textbooks, or videos?".

To answer this question, we included a custom questionnaire A.2 in both the user evaluation session. Therefore, in addition to answering the SUS, participants were asked to respond to a questionnaire A.2, specifically created to gauge students' and users' perceptions of the use of VR in pharmacology education.

The respondents generally agreed with each other for most of the statements. The results indicate strong agreement from the vast majority of the respondents that using a VR application in pharmacology education can make learning more engaging and interactive and that a VR application provides meaningful benefits compared to traditional teaching methods such as books, lectures, and videos. One item on the questionnaire where the respondents were not in agreement was question 8 A.20. The answers to the statement, "The benefits of using a VR application in my field of study does not outweigh the challenges and limitations", varied the most. Responses spanned the entire spectrum of opinions, ranging from "strongly disagree" to "strongly agree".

The majority of evaluation participants were in agreement when responding to items one and two of the custom questionnaire. To the statement, "Using a VR application in pharmacology education can make learning more engaging and interactive.", 12 of the 13 respondents answered "strongly agree" and one respondent answered "agree". Similarly, every participant disagreed with the statement, "A VR application does not provide any meaningful benefits compared to traditional teaching methods such as books, lectures, and videos."

The data shows that both students and educators strongly believe that using a VR application in pharmacology education can significantly enhance the engagement and interactivity of the learning process. The overwhelming agreement with the statement emphasises the potential of VR to transform the educational experience by providing a more immersive and interactive environment. Additionally, the unanimous disagreement with the notion that VR lacks meaningful benefits compared to traditional teaching methods demonstrates the recognition of VR's unique advantages to pharmacology education. These findings suggest a shared belief among participants that VR can offer valuable enhancements to teaching and learning practices.

Every participant reported either "agree" or "strongly agree" with the statement, "The use of a VR application in pharmacology education can provide a more immersive and memorable learning experience." This unanimous agreement aligns with the findings of several studies mentioned in Section 1.4, which have highlighted the potential of VR to offer an immersive and interactive learning environment. In addition, there are also studies suggesting that immersive virtual environments can offer major advantages in the domain of visual-spatial learning [132].

Question 8 of the custom questionnaire, which examines the assertion that "The benefits of utilising a VR application in the context of my field of study do not outweigh the challenges and limitations," yielded the most diverse responses. This finding suggests that participants hold varying perspectives regarding the balance between the advantages and disadvantages of utilising a VR application within their respective fields of study. Some might worry about technical problems or costs, such as the steep learning curve often associated with new technologies or the investment in VR equipment. Others might feel that these challenges are outweighed by the potential benefits, such as increased engagement, interactivity, and enhanced understanding of complex concepts that VR can offer.

This diversity in opinions suggests that while there is enthusiasm for VR applications in pharmacology education, there are also concerns about potential difficulties that need to be addressed.

The practicalities of integrating VR into an educational setting present some challenges. Access to VR equipment and cost are just some limiting factors [36]. Lie et al. [36] state that it is necessary to provide sufficient time for both students and faculty to adjust when implementing and using virtual reality in health professions education.

As VR continues to evolve, it has the potential to become an influential tool in the broader pedagogical toolbox. One approach could be to utilise VR as a supplemental tool to reinforce previously taught material. After a lecture or reading assignment, students could use the application to revisit and deepen their understanding of the concepts. On the other hand, the application could be used more flexibly, with students encouraged to explore at their own pace and focus on areas they find particularly challenging.

Although the response from the user study was predominantly positive, it is important to acknowledge that the sample size was relatively small. While the feedback provides valuable insights into the perceptions of VR in pharmacology education, it may not fully represent the views of the broader population. Furthermore, the diversity of learning styles and preferences means that a broader study could reveal additional insights.

As elaborated in the prior section, the methodology we utilised to create this VR application was just one of many possible approaches. The construction of an application for this unique context involves a vast array of choices. It is crucial to acknowledge that the chosen method is not necessarily the optimal or only pathway, and other valid strategies may exist. Variations in the design approach could potentially lead to an enhanced level of understanding or engagement among students.

While the questionnaire statements aimed to assess respondents' perspectives on VR in a general sense, it is important to consider that the answers might have been influenced by the specific VR application developed within this project. This potential influence stems from the fact that evaluation participants were asked to interact with and evaluate our application prior to completing the custom questionnaire.

It is important to note that the developed application, although offering a glimpse into the utilisation of VR for showcasing pharmacological aspects in a virtual environment, may not represent the cutting-edge advancements in VR technology. If participants had the opportunity to experience a similar application created by a prominent company, their responses to the questionnaire statements might have been more favorable.

Conversely, participants might have held more positive perceptions, envisioning that the application would be significantly improved in its final form. In this case, one would need to consider the respondents' anticipations for future development while interpreting the questionnaire results.

Either way, when interpreting the results, one should keep the context of the evaluation session and the developed proof of concept application in mind.

It is recommended that further research be conducted with a larger and more diverse sample size to gain a more comprehensive and reliable understanding of the benefits and limitations. This will help to determine not only the overall efficacy of VR as a tool in pharmacology education but also the contexts and settings in which it may be most beneficial.

Alongside this, it would be beneficial to continue evolving the application based on the feedback and suggestions from the participants. Such iterative improvements would allow the application to better suit the needs of different learners and educators alike.

Due to the mixed responses regarding the challenges and limitations of VR, it would be valuable to investigate these concerns further, identifying the specific challenges encountered by users and developing strategies to mitigate them. Moreover, exploring ways to integrate the VR application seamlessly with traditional methods would also be a worthwhile pursuit.

Our research has explored the perceived effectiveness of a VR application in pharmacology education compared to traditional methods. The empirical evidence showed strong agreement among participants regarding VR's ability to provide immersive and memorable learning experiences. However, there were varied responses regarding the balance of benefits and challenges associated with the implementation of VR in the specific domain of pharmacology education.

All but one participant expressed "strong agreement" to notion that using a VR application in pharmacology education can make learning more engaging and interactive. Similarly, all participants expressed agreement with the proposition that VR offers substantial advantages in comparison to conventional teaching methods such as textbooks, lectures, and videos.

Based on the evaluation results and in response to Research Question 2, it can be argued that both pharmacology students and educators perceive VR as a valuable tool that offers advantages over traditional teaching methods in the context of pharmacology education.

6.4 Further work

6.4.1 Improvements to the Application

The application developed during this project holds immense potential for future improvements. This includes enhancing the user experience, deepening learning outcomes, and enabling more complex visualisations of pharmacological concepts.

The world of technology is in a perpetual state of progress, and this forward momentum carries a wealth of opportunities for refining and expanding the capabilities of such VR applications. One key area of improvement lies in the models used in the application. As technology continues to advance, more detailed and accurate 3D models are constantly being developed. These can eventually represent intricate biological structures with unprecedented precision, enabling visualisation of the smallest components inside the human body. The leap in detail and accuracy can significantly enhance both the realism and the educational potential of the application.

Similarly, the power and efficiency of VR headsets are continually evolving. In the future, it is expected that headsets will become even more powerful, with increased resolution displays, improved frame rates, and enhanced tracking capabilities. This growing processing power will allow developers to incorporate more complex mechanisms and systems into their applications.

Feedback from the evaluation phase revealed a desire among participants for more complex visualisations, particularly at the cellular level. This underscores the importance of leveraging technological advancements to deliver a richer, more detailed learning experience. The continuous improvements in VR technology allow for more complex simulations, including highly detailed models and advanced animation. It might be possible to expand the application to include such intricate simulations, enabling users to observe the cellular interactions of medications.

Another proposed enhancement, suggested during the evaluation, was the inclusion of multiple-choice questions. This could serve to reinforce the knowledge acquired from the simulations. For example, after completing a simulation of how a beta-2-agonist works, the user could be presented with a quiz testing their understanding of the medication's effects and its role in asthma treatment. This would not only make the learning experience more interactive but also provide immediate feedback on the user's comprehension. Such feedback could serve a dual purpose - it would help consolidate the user's learning and could also act as an informative tool for educators, helping them identify any areas of misunderstanding or gaps in the learner's knowledge that need to be addressed.

In consultation with Berg and Serkland, the idea of integrating a gamified component into the application has been proposed as a desired direction for future development. They propose that users could virtually administer different medications, with the simulation accurately reflecting the outcomes of their treatment choices. This could include situations such as administering the correct medication versus an incorrect one or adjusting dosage levels to see the effects of under or over-medication. This interactive component would provide students with a risk-free environment to apply their knowledge and experience the real-world implications of their decisions.

6.4.2 Expansion of Diseases

There is a vast landscape of possibilities to broaden the application's capabilities. Currently, the VR application focuses on visualising the pharmacological effects of beta-2-agonists in the treatment of acute asthma attacks, a condition within the broader spectrum of human diseases. However, the principles applied in this application can potentially be extended to a host of other diseases, each with unique health-related characteristics and treatment methods.

Toward the conclusion of the project period, our stakeholders expressed an interest in incorporating long-term control medications for asthma as the next step in the project. This, together with the already implemented short-acting medication, could give a broader understanding of the complex nature of asthma management.

The results gathered from the study indicate a positive reception from participants, who found the application an engaging and motivating tool for learning pharmacology. An expansion to cover a broader range of diseases could significantly enhance the application's utility and relevance, making it more suitable for various pharmacology topics. It is conceivable that the more expansive and relevant the application becomes, the greater its chances of being adopted as an additional tool in education. By supplementing traditional teaching methods with a tool like this, educators could potentially boost student interest and motivation in pharmacology.

It is important to note that this expansion would require careful planning and execution to ensure each disease is accurately represented and the complexity of the application remains manageable for users. A crucial aspect of this process would be the involvement of medical experts. Having precise information from these experts would be invaluable in guaranteeing the accurate visualisation of each disease, thereby providing the highest educational value to the students using the application.

6.5 Limitations

In the process of developing an educational tool that takes advantage of VR technology, it is essential to acknowledge the inherent limitations that come with the territory. The following points highlight some of the constraints encountered during the project.

Firstly, the level of detail and realism achievable in the 3D models is constrained by the processing power of current VR headsets. High-fidelity models with intricate details can significantly increase the computational demand, leading to performance issues such as low frame rates or latency. Although efforts were made to optimise the models for the VR environment, a careful balance between detail and performance had to be maintained.

Secondly, the UI and the user experience design in VR applications present unique challenges compared to traditional software design. Ensuring the application is intuitive and user-friendly, particularly for users who may be unfamiliar with VR technology, is crucial. Despite careful design and user testing, there may be aspects of the UI or UX that some users find less intuitive or more challenging to navigate, as discovered during the user evaluation.

The scope of the application is another aspect worth mentioning. Currently, it is primarily focused on the pharmacological treatment of asthma, with an emphasis on the action of short-acting beta-2-agonists. While this focus allows for a detailed exploration of this particular aspect of asthma treatment, it does not provide a comprehensive view of asthma management or cover other essential topics in pharmacology. This limitation was a conscious decision made in the project's scope to ensure depth of content over breadth.

The application's effectiveness as an educational tool is dependent on the user's engagement with the material, which can be influenced by numerous factors. These factors may include personal preference, familiarity with VR, and the quality of the VR hardware used. Although VR provides an immersive and interactive learning experience, it does not guarantee that all users will find it more effective or engaging than traditional learning methods.

Chapter 7

Conclusion

This thesis aimed to design a VR application that would enable users to simulate the pharmacological effects of medicinal drugs and observe these effects within the human body. In the early stages of the project, the focus was narrowed down to asthma medication, specifically quick-acting beta-2-agonists, in order to limit the scope of the project and ensure a more focused approach to the simulation development. This allowed for a more detailed and comprehensive exploration of the specific medication and its effects on the body, leading to a more accurate and informative VR experience for users. The decision led to the creation of an application that served as a proof of concept for a larger application encompassing a broader range of medications. The project's design and development processes were centred around achieving a high degree of realism and accuracy, with the ultimate aim of producing an application that would aid in medical education and training.

This thesis was centred around two research questions:

- **RQ1: How can we design a Virtual Reality simulation that enables users to observe the pharmacological effects of beta-2-agonists in the treatment of asthma?**
- **RQ2: How do students perceive the effectiveness of VR applications in helping them learn pharmacology concepts compared to traditional teaching methods such as lectures, textbooks, or videos?**

To develop and evaluate the application, the principles of Design Science were employed. In Chapter 4, the response to RQ1 is presented, and some significant insights are highlighted in Chapter 6. While we do not claim that our design is the sole or optimal method to construct such an application, it does provide a response to the stated research inquiry. Furthermore, as discussed in Chapter 3, to assess the usability and effectiveness of the designed application, a SUS questionnaire was utilised in the user evaluation process. The results presented in Chapter 5 shows that the application achieved a SUS score of 82.5 in the first evaluation and 80.55 in the second evaluation, indicating that it was perceived as usable. This suggests that our design is, at least, a viable method for simulating the pharmacological effects of beta-2-agonists in the treatment of asthma in a VR environment.

In addition to the SUS, a custom questionnaire was developed to evaluate the perceived effectiveness of the VR application in helping students learn pharmacology concepts compared to traditional teaching methods. The findings from this evaluation were presented in Chapter 5 and discussed in Chapter 6, providing an answer to RQ2.

This thesis has also delved into potential future prospects with regards to the project. In particular, the possibilities of broadening the scope of the application to encompass a greater range of medications, and utilising the research as a foundation for more extensive studies focused on aspects such as learning outcomes. These future avenues hold potential for expanding the application's utility and uncovering further insights on the efficacy of virtual reality in pharmacology education.

In conclusion, the present study has successfully developed and tested a functional implementation of the proposed VR application using the principles of design science. The resulting application underwent evaluation using both quantitative and qualitative methods, indicating its viability and usability for medical education and training. The findings of this study contribute to the growing body of literature on the use of VR technology for medical education and training, and may provide a valuable foundation for future research in this area.

Appendix A

Evaluation Results

A.1 SUS Results

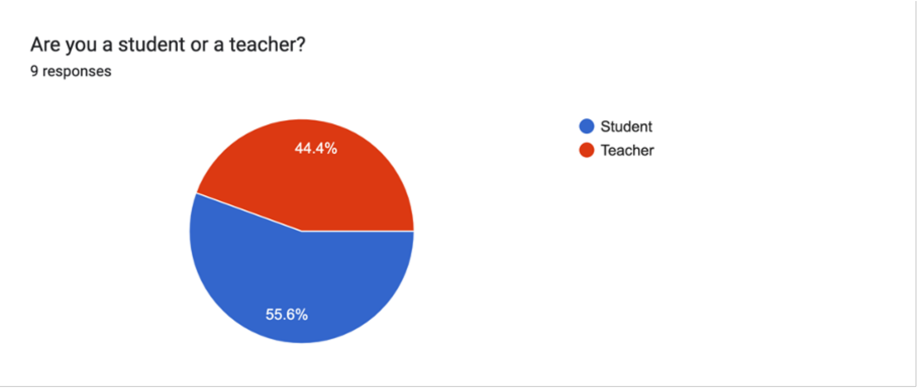


Figure A.1: Pre-question 1

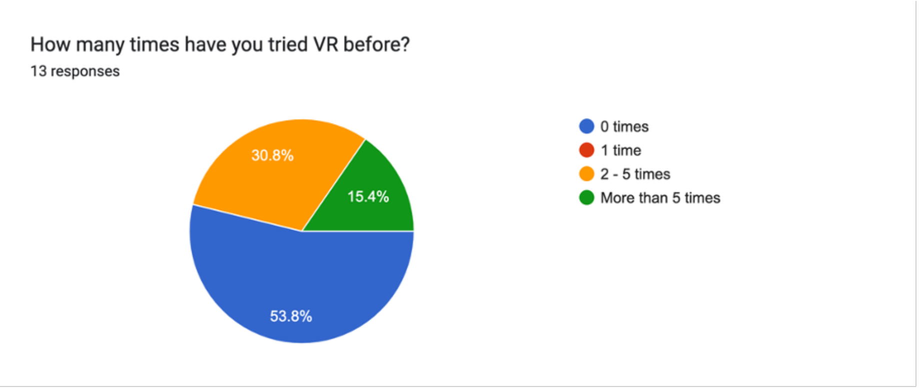


Figure A.2: Pre-question 2

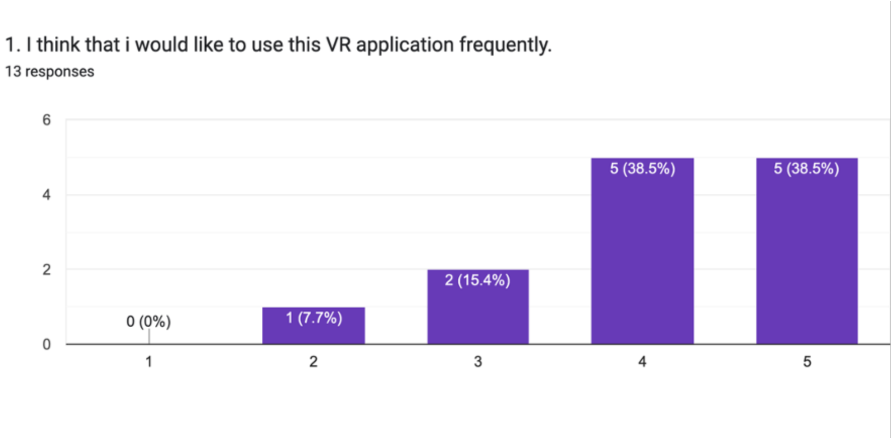


Figure A.3: Question 1, SUS

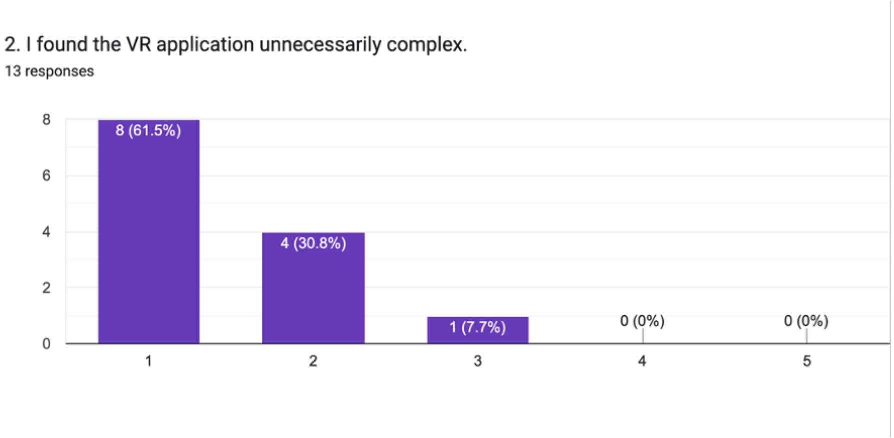


Figure A.4: Question 2, SUS

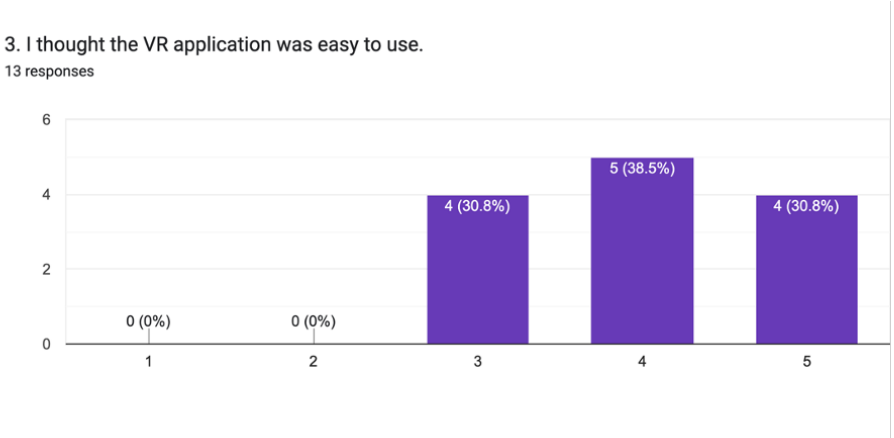
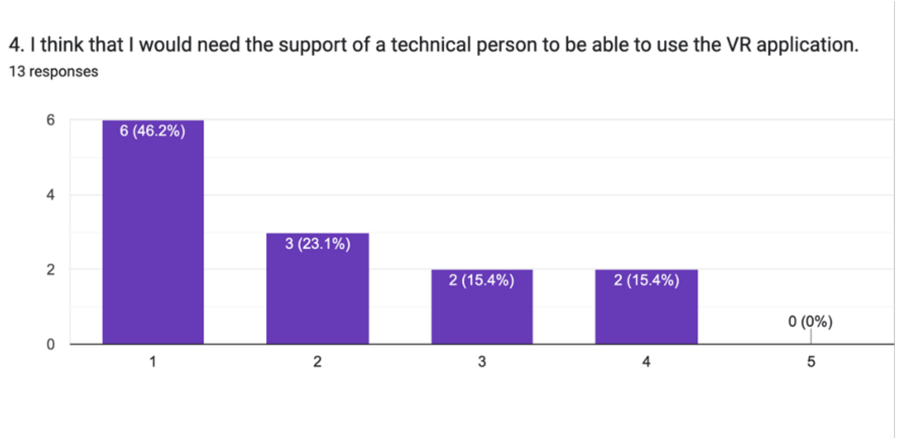


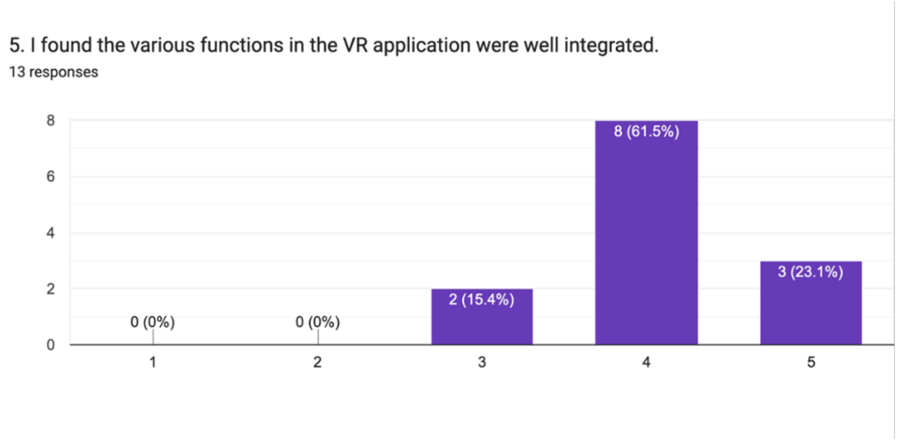
Figure A.5: Question 3, SUS



4. I think that I would need the support of a technical person to be able to use the VR application.

13 responses

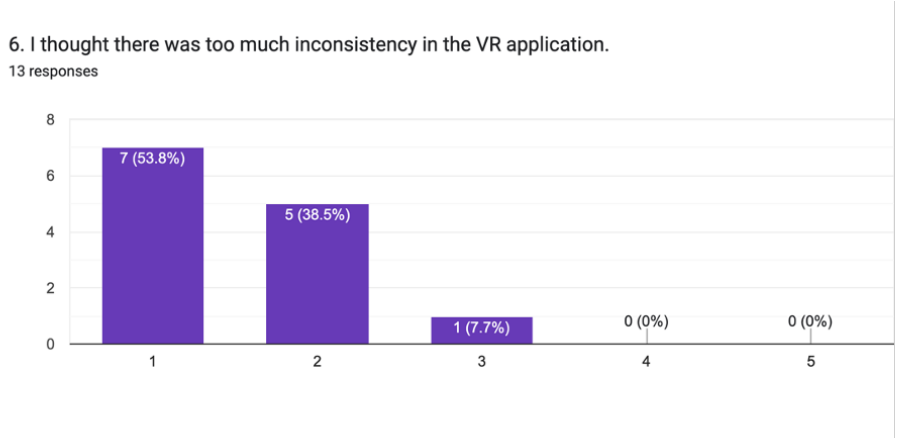
Figure A.6: Question 4, SUS



5. I found the various functions in the VR application were well integrated.

13 responses

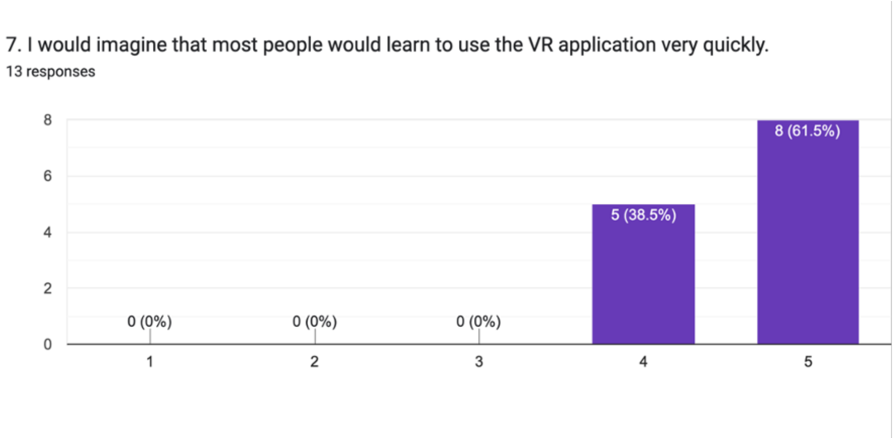
Figure A.7: Question 5, SUS



6. I thought there was too much inconsistency in the VR application.

13 responses

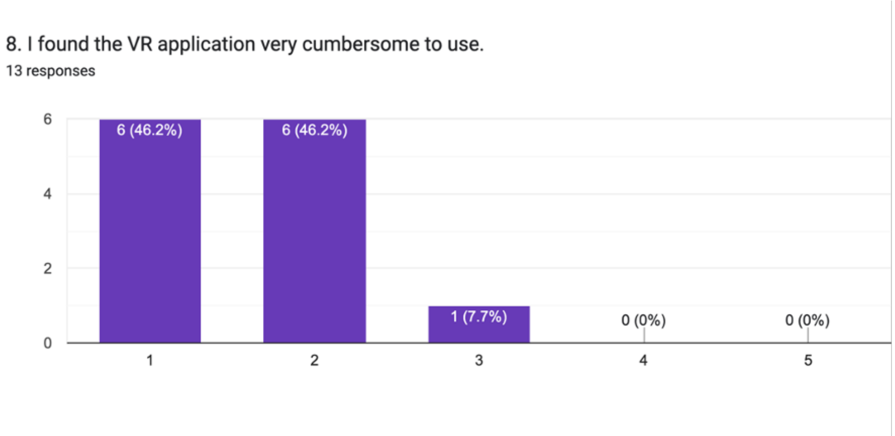
Figure A.8: Question 6, SUS



7. I would imagine that most people would learn to use the VR application very quickly.

13 responses

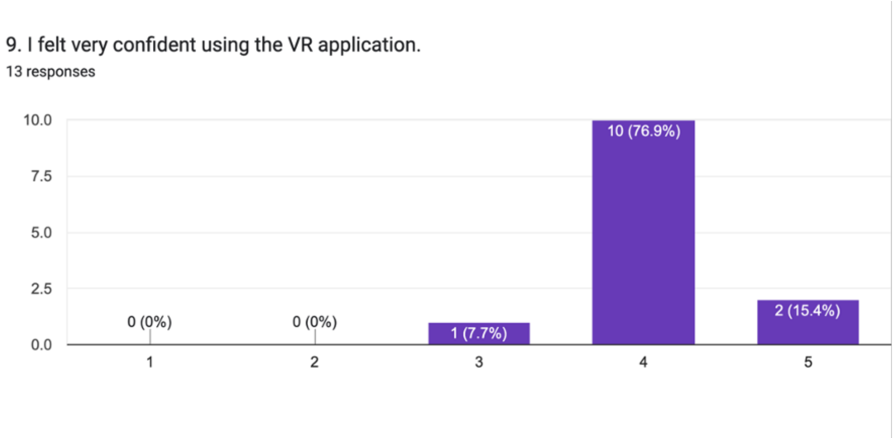
Figure A.9: Question 7, SUS



8. I found the VR application very cumbersome to use.

13 responses

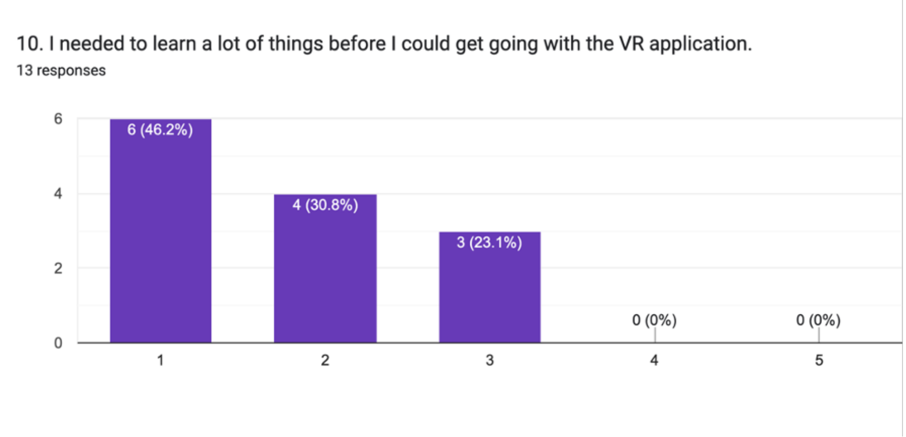
Figure A.10: Question 8, SUS



9. I felt very confident using the VR application.

13 responses

Figure A.11: Question 9, SUS

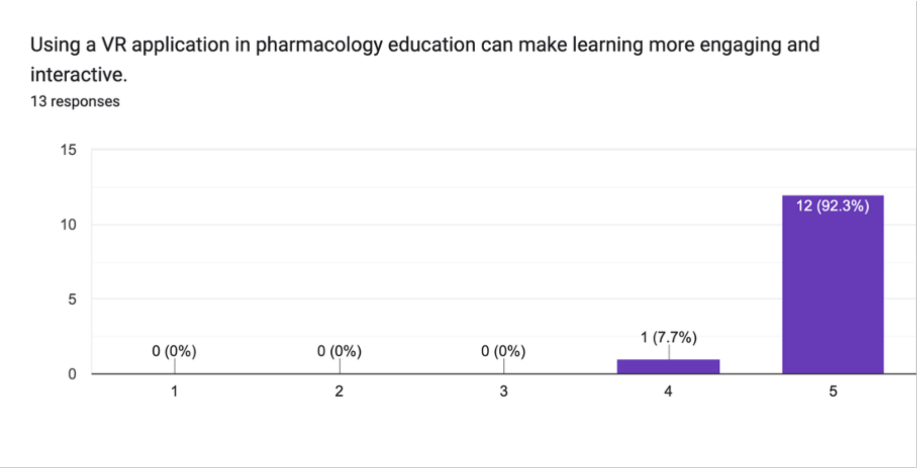


10. I needed to learn a lot of things before I could get going with the VR application.

13 responses

Figure A.12: Question 10, SUS

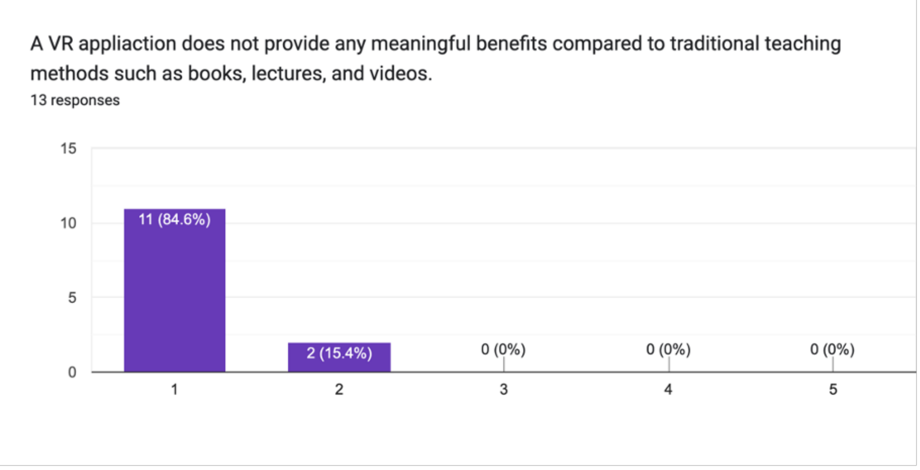
A.2 Custom Questionnaire



Using a VR application in pharmacology education can make learning more engaging and interactive.

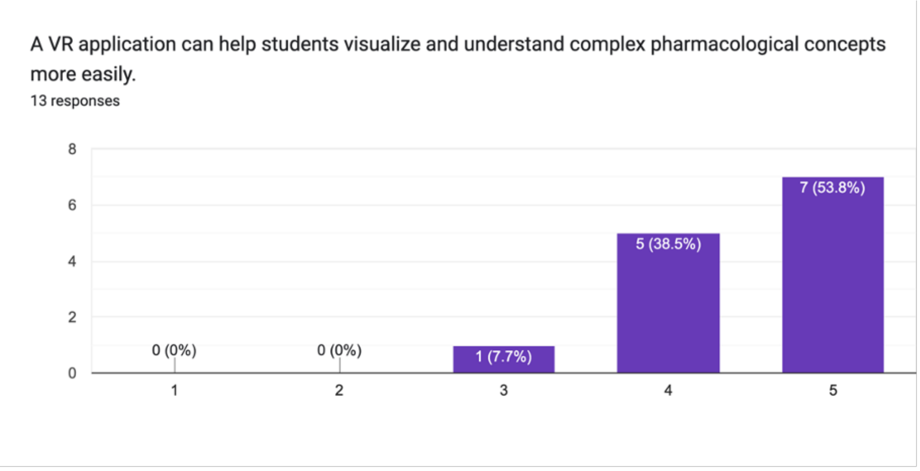
13 responses

Figure A.13: Question 1, Custom Questionnaire


A VR appliaction does not provide any meaningful benefits compared to traditional teaching methods such as books, lectures, and videos.

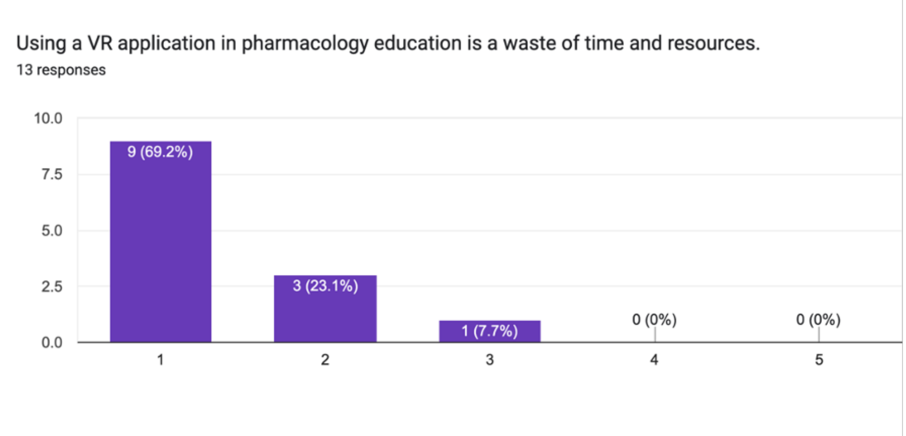
13 responses

Figure A.14: Question 2, Custom Questionnaire


A VR application can help students visualize and understand complex pharmacological concepts more easily.

13 responses

Figure A.15: Question 3, Custom Questionnaire


Using a VR application in pharmacology education is a waste of time and resources.

13 responses

Figure A.16: Question 4, Custom Questionnaire

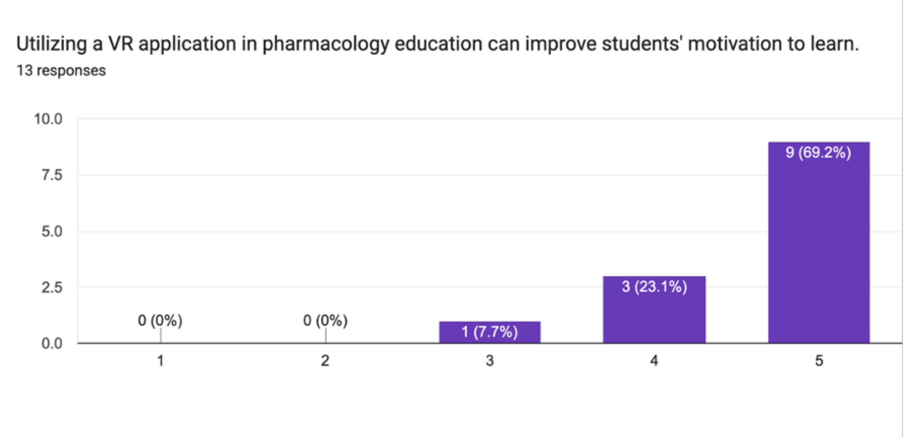


Figure A.17: Question 5, Custom Questionnaire

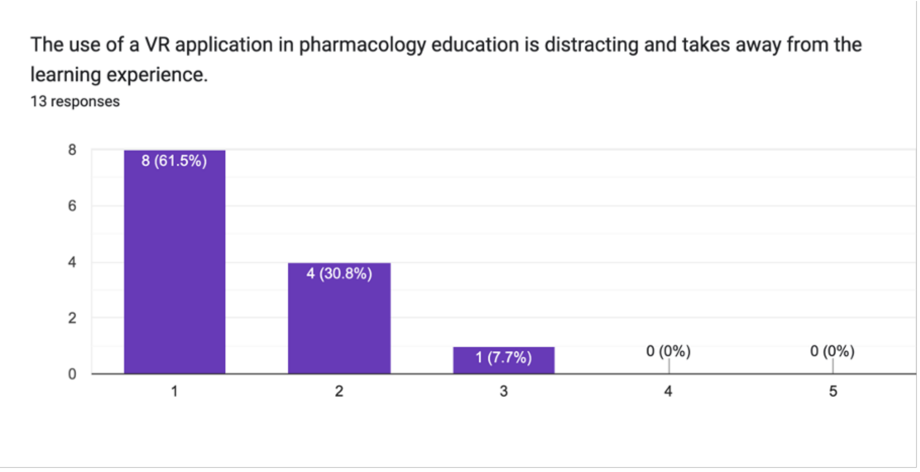


Figure A.18: Question 6, Custom Questionnaire

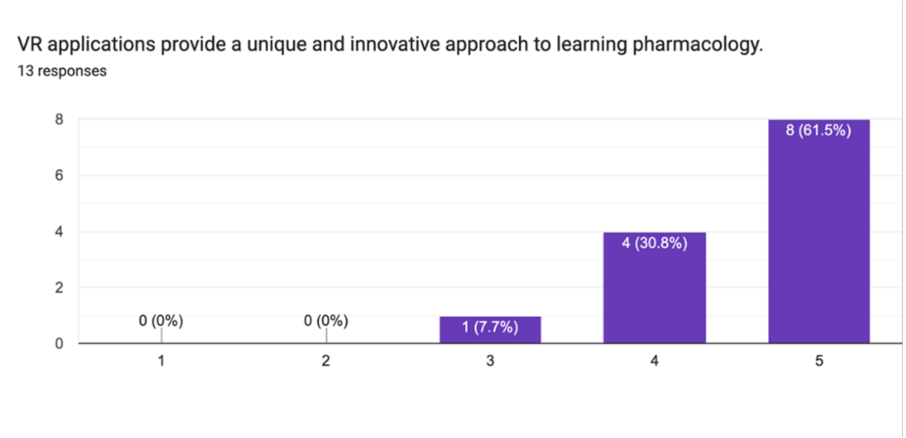


Figure A.19: Question 7, Custom Questionnaire

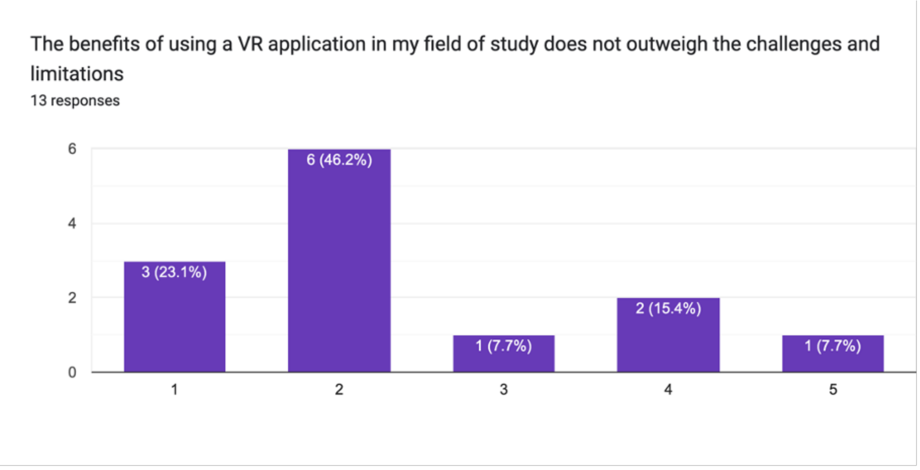


Figure A.20: Question 8, Custom Questionnaire

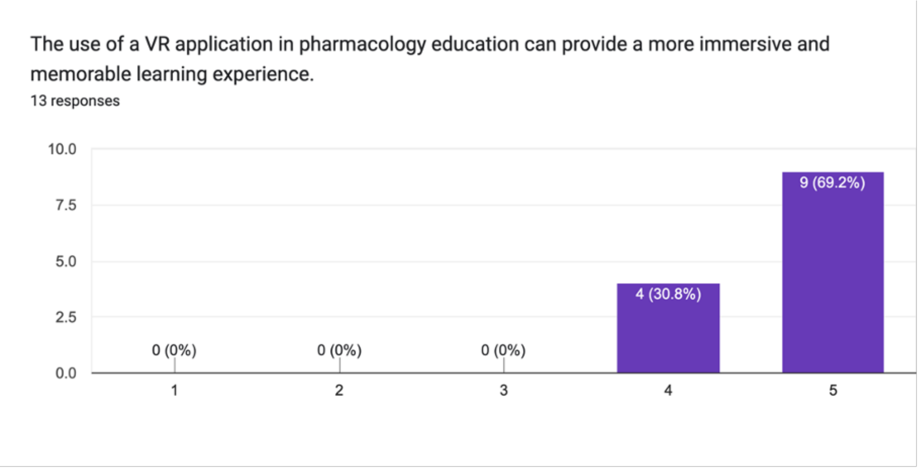


Figure A.21: Question 9, Custom Questionnaire

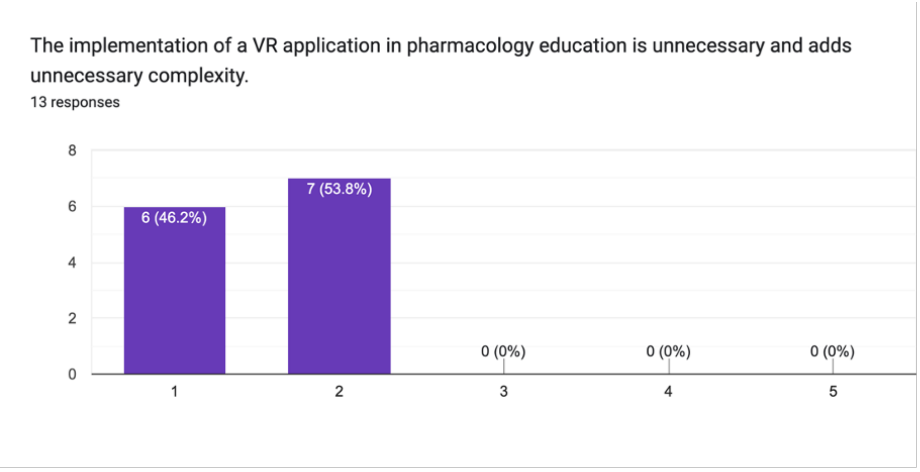


Figure A.22: Question 10, Custom Questionnaire

Appendix B

Source code

The source code for the application is available at this URL: `https://github.com/avlesbug/VR-Pharmacology`.

A video showcasing the application is available at this URL: `https://youtu.be/gkEHYkIN1fc`.

A Windoes build of the application can be downloaded at this URL: `https://drive.google.com/file/d/1WMU7s611ttAh3OTCX2dJKQd8hvmdIRAX/view?usp=sharing`.

Bibliography

[1] C Moates. "VR is the Future of Education." In: (2020). URL: `https://www.gmw3.com/2021/06/vr-is-the-future-of-education/` (visited on Mar. 22, 2022).

[2] Nikolaos Pellas, Stylianos Mystakidis, and Ioannis Kazanidis. "Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature." In: *Virtual Reality* 25.3 (Sept. 1, 2021), pp. 835–861. ISSN: 1434-9957. DOI: `10.1007/s10055-020-00489-9`. URL: `https://doi.org/10.1007/s10055-020-00489-9` (visited on Jan. 5, 2023).

[3] Hassan Aziz. "Virtual Reality Programs Applications in Healthcare." In: *Journal of Health & Medical Informatics* 9 (Mar. 12, 2018), p. 305. DOI: `10.4172/2157-7420.1000305`.

[4] Lucia R. Valmaggia et al. "Virtual reality in the psychological treatment for mental health problems: An systematic review of recent evidence." In: *Psychiatry research* 236 (2016). Place: CLARE Publisher: Elsevier B.V, pp. 189–195. ISSN: 0165-1781. DOI: `10.1016/j.psychres.2016.01.015`.

[5] Emily Carl et al. "Virtual reality exposure therapy for anxiety and related disorders: A meta-analysis of randomized controlled trials." In: *Journal of Anxiety Disorders* 61 (Jan. 2019), pp. 27–36. ISSN: 08876185. DOI: `10.1016/j.janxdis.2018.08.003`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0887618518302469` (visited on Apr. 18, 2023).

[6] Leanne Coyne et al. "The Past, Present, and Future of Virtual Reality in Pharmacy Education." In: *American Journal of Pharmaceutical Education* 83.3 (Apr. 2019), p. 7456. ISSN: 0002-9459, 1553-6467. DOI: `10.5688/ajpe7456`. URL: `http://www.ajpe.org/lookup/doi/10.5688/ajpe7456` (visited on Sept. 19, 2022).

[7] Hedvig Nordeng and Johannes Setekleiv. "farmakologi." In: (2020). URL: `https://sml.snl.no/farmakologi` (visited on Mar. 15, 2022).

[8] *IV Therapy Vs Oral Supplements: Which One Is Better?* en-US. Dec. 2021. URL: `https://www.urgentcaretexas.com/iv-therapy-vs-oral-supplements/` (visited on Sept. 16, 2022).

[9] Bhone Myint Kyaw et al. "Virtual reality for health professions education: Systematic review and meta-analysis by the digital health education collaboration." In: *Journal of medical Internet research* 21.1 (2019). Place: Canada Publisher: JMIR Publications, e12959–e12959. ISSN: 1438-8871. DOI: `10.2196/12959`.

[10] Bobbi Shatto and Kelly Erwin. “Teaching Millennials and Generation Z: Bridging the Generational Divide.” In: *Creative Nursing* 23.1 (Feb. 1, 2017), pp. 24–28. ISSN: 1078-4535. DOI: `10.1891/1078-4535.23.1.24`.

[11] Sanaa Ashour. “How technology has shaped university students’ perceptions and expectations around higher education: an exploratory study of the United Arab Emirates.” In: *Studies in higher education (Dorchester-on-Thames)* 45.12 (2020). Place: Abingdon Publisher: Routledge, pp. 2513–2525. ISSN: 0307-5079. DOI: `10.1080/03075079.2019.1617683`.

[12] A. Hilal Bati et al. “Why do students miss lectures? A study of lecture attendance amongst students of health science.” In: *Nurse Education Today* 33.6 (June 2013), pp. 596–601. ISSN: 1532-2793. DOI: `10.1016/j.nedt.2012.07.010`.

[13] Putul Mahanta et al. “Indian medical undergraduates’ perceptions of effective teaching methods: A cross-sectional study.” eng. In: *Advances in medical education and practice* 12 (2021). Place: New Zealand Publisher: Dove Medical Press Limited, pp. 473–479. ISSN: 1179-7258. DOI: `10.2147/AMEP.S306598`. URL: `http://dx.doi.org/10.2147/AMEP.S306598` (visited on Sept. 16, 2022).

[14] Chen-Lin Xiao et al. “Multidimensional evaluation of teaching strategies for pharmacology based on a comprehensive analysis involving 21,269 students.” In: *Frontiers in Pharmacology* 14 (2023). URL: `https://www.frontiersin.org/articles/10.3389/fphar.2023.1145456/full` (visited on May 24, 2023).

[15] Paul Supper et al. “A concept for adapting medical education to the next generations via three-staged digital peer teaching key feature cases.” In: *Wiener Medizinische Wochenschrift (1946)* 173.5 (Apr. 2023), pp. 108–114. ISSN: 1563-258X. DOI: `10.1007/s10354-022-00990-7`.

[16] PantherMedia/Gorodenkoff. URL: `https://healthcare-mittelhessen.eu/trend-report-virtual-reality-digital-training-for-real-medicine?lang=en`.

[17] Lucinda Kerawalla et al. ““Making it real”: exploring the potential of augmented reality for teaching primary school science.” en. In: *Virtual Reality* 10.3 (Dec. 2006), pp. 163–174. ISSN: 1434-9957. DOI: `10.1007/s10055-006-0036-4`. URL: `https://doi.org/10.1007/s10055-006-0036-4` (visited on Sept. 16, 2022).

[18] Matias N. Selzer, Nicolas F. Gazcon, and Martin L. Larrea. “Effects of virtual presence and learning outcome using low-end virtual reality systems.” en. In: *Displays* 59 (Sept. 2019), pp. 9–15. ISSN: 01419382. DOI: `10.1016/j.displa.2019.04.002`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0141938218300398` (visited on Sept. 16, 2022).

[19] Chelsea Ekstrand et al. “Immersive and interactive virtual reality to improve learning and retention of neuroanatomy in medical students: a randomized controlled study.” In: *Canadian Medical Association Open Access Journal* 6.1 (2018), E103–E109.

[20] Jingjie Zhao et al. “The effectiveness of virtual reality-based technology on anatomy teaching: a meta-analysis of randomized controlled studies.” In: *BMC medical education* 20.1 (2020), pp. 1–10. URL: `https://bmcmededuc.biomedcentral.com/articles/10.1186/s12909-020-1994-z`.

[21] Philip Hardie et al. "Nursing & Midwifery students' experience of immersive virtual reality storytelling: an evaluative study." In: *BMC Nursing* 19.1 (Aug. 17, 2020), p. 78. ISSN: 1472-6955. DOI: `10.1186/s12912-020-00471-5`. URL: `https://doi.org/10.1186/s12912-020-00471-5` (visited on May 31, 2023).

[22] Michael Prince. "Does Active Learning Work? A Review of the Research." In: *Journal of Engineering Education* 93.3 (2004), pp. 223–231. ISSN: 2168-9830. DOI: `10.1002/j.2168-9830.2004.tb00809.x`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2168-9830.2004.tb00809.x` (visited on May 31, 2023).

[23] Ntombifikile Gloria Mtshali and Alexis Harerimana. "Nursing students' perceptions and expectations regarding the use of technology in nursing education." In: *Africa journal of nursing and midwifery.* 21.2 (2019). Publisher: UNISA Press, pp. 1–20. ISSN: 1682-5055. DOI: `10.25159/2520-5293/5103`.

[24] Office of the Commissioner. "Fact Sheet: FDA at a Glance." In: *FDA* (Aug. 17, 2022). Publisher: FDA. URL: `https://www.fda.gov/about-fda/fda-basics/fact-sheet-fda-glance` (visited on Apr. 19, 2023).

[25] Lasse Jensen and Flemming Konradsen. "A review of the use of virtual reality head-mounted displays in education and training." In: *Education and Information Technologies* 23.4 (July 2018), pp. 1515–1529. ISSN: 1360-2357, 1573-7608. DOI: `10.1007/s10639-017-9676-0`. URL: `http://link.springer.com/10.1007/s10639-017-9676-0` (visited on Jan. 25, 2023).

[26] Guido Makransky, Thomas S. Terkildsen, and Richard E. Mayer. "Adding immersive virtual reality to a science lab simulation causes more presence but less learning." In: *Learning and Instruction* 60 (Apr. 2019), pp. 225–236. ISSN: 09594752. DOI: `10.1016/j.learninstruc.2017.12.007`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0959475217303274` (visited on Jan. 26, 2023).

[27] "Games on mobiles via web or virtual reality technologies: How to support learning for biomedical laboratory science education." In: (2020). Publisher: MDPI. ISSN: 2078-2489. DOI: `https://doi.org/10.3390/info11040195`. URL: `https://hdl.handle.net/11250/2689971` (visited on Jan. 25, 2023).

[28] Nancy A. Baker et al. "The State of Science in the Use of Virtual Reality in the Treatment of Acute and Chronic Pain: A Systematic Scoping Review." In: *The Clinical journal of pain* 38.6 (2022). Place: United States Publisher: Lippincott Williams & Wilkins, WK Health, pp. 424–441. ISSN: 1536-5409. DOI: `10.1097/AJP.0000000000001029`.

[29] Sydney Hemphill et al. "Virtual Reality Augments Movement During Physical Therapy: A Pragmatic Randomized Trial." In: *American journal of physical medicine & rehabilitation* 101.3 (2022). Place: United States Publisher: Lippincott Williams & Wilkins, WK Health, pp. 229–236. ISSN: 1537-7385. DOI: `10.1097/PHM.0000000000001779`.

[30] Pablo Campo-Prieto, José María Cancela, and Gustavo Rodríguez-Fuentes. "Immersive virtual reality as physical therapy in older adults: present or future (systematic review)." In: *Virtual reality : the journal of the Virtual Reality Society* 25.3 (2021). Place: London Publisher: Springer London, pp. 801–817. ISSN: 1359-4338. DOI: `10.1007/s10055-020-00495-x`.

[31] Gustavo Saposnik, Mindy Levin, and for the Stroke Outcome Research Canada (SORCan) Working Group. “Virtual Reality in Stroke Rehabilitation: A Meta-Analysis and Implications for Clinicians.” In: *Stroke* 42.5 (May 2011), pp. 1380–1386. ISSN: 0039-2499, 1524-4628. DOI: `10.1161/STROKEAHA.110.605451`. URL: `https://www.ahajournals.org/doi/10.1161/STROKEAHA.110.605451` (visited on Apr. 18, 2023).

[32] Robert Winter and Antonia Albani. “Restructuring the Design Science Research Knowledge Base: A One-Cycle View of Design Science Research and its Consequences for Understanding Organizational Design Problems.” In: *Designing Organizational Systems*. Ed. by Richard Baskerville, Marco De Marco, and Paolo Spagnoletti. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 63–81. ISBN: 978-3-642-33370-5 978-3-642-33371-2. DOI: `10.1007/978-3-642-33371-2_4`. URL: `https://link.springer.com/10.1007/978-3-642-33371-2_4` (visited on Apr. 14, 2023).

[33] Giuseppa Maresca et al. “A novel use of virtual reality in the treatment of cognitive and motor deficit in spinal cord injury: A case report.” In: *Medicine* 97.50 (Dec. 2018), e13559. ISSN: 1536-5964. DOI: `10.1097/MD.0000000000013559`.

[34] Lars Clemmensen et al. “Study protocol: Exposure in virtual reality for social anxiety disorder-a randomized controlled superiority trial comparing cognitive behavioral therapy with virtual reality based exposure to cognitive behavioral therapy with in vivo exposure.” In: *BMC psychiatry* 20.1 (2020). Place: England Publisher: BioMed Central, pp. 32–32. ISSN: 1471-244X. DOI: `10.1186/s12888-020-2453-4`.

[35] Philip Lindner et al. “How to treat depression with low-intensity virtual reality interventions: Perspectives on translating cognitive behavioral techniques into the virtual reality modality and how to make antidepressive use of virtual reality–unique experiences.” In: *Frontiers in psychiatry* 10 (2019). Publisher: Frontiers Research Foundation, pp. 792–792. ISSN: 1664-0640. DOI: `10.3389/fpsyt.2019.00792`.

[36] Silje Stangeland Lie et al. “Implementation of Virtual Reality in Health Professions Education: Scoping Review.” In: *JMIR medical education* 9 (Jan. 24, 2023), e41589. ISSN: 2369-3762. DOI: `10.2196/41589`.

[37] Haowen Jiang et al. “Virtual Reality in Medical Students’ Education: Scoping Review.” In: *JMIR Medical Education* 8.1 (Feb. 2, 2022), e34860. ISSN: 2369-3762. DOI: `10.2196/34860`. URL: `https://mededu.jmir.org/2022/1/e34860` (visited on May 23, 2023).

[38] Dung-Hung Chiang et al. “Immersive virtual reality (VR) training increases the self-efficacy of in-hospital healthcare providers and patient families regarding tracheostomy-related knowledge and care skills A prospective pre-post study.” In: *Medicine (Baltimore)* 101.2 (2022). Place: United States Publisher: Lippincott Williams & Wilkins, WK Health, E28570–e28570. ISSN: 0025-7974. DOI: `10.1097/MD.0000000000028570`.

[39] Kelly L. Rossler, Ganesh Sankaranarayanan, and Mariana H. Hurutado. “Developing an immersive virtual reality medication administration scenario using the nominal group technique.” In: *Nurse Education in Practice* 56 (Oct. 2021), p. 103191. ISSN: 14715953. DOI: `10.1016/j.nepr.2021.103191`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S1471595321002274` (visited on Sept. 19, 2022).

[40] Christian Plotzky et al. "Virtual reality simulations in nurse education: A systematic mapping review." In: *Nurse Education Today* 101 (June 1, 2021), p. 104868. ISSN: 0260-6917. DOI: `10.1016/j.nedt.2021.104868`. URL: `https://www.sciencedirect.com/science/article/pii/S0260691721001258` (visited on May 24, 2023).

[41] Martin Reznek, Phillip Harter, and Thomas Krummel. "Virtual Reality and Simulation: Training the Future Emergency Physician." In: *Academic Emergency Medicine* 9.1 (2002), pp. 78–87. ISSN: 1553-2712. DOI: `10.1197/aemj.9.1.78`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1197/aemj.9.1.78` (visited on May 31, 2023).

[42] Christian Moro et al. "The effectiveness of virtual and augmented reality in health sciences and medical anatomy." In: *Anatomical sciences education* 10.6 (2017), pp. 549–559.

[43] VISITING ADDRESS Søsterhjemmet, Kirkeveien 166, and 2 etasje0450 OSLO Norway MAIL ADDRESS P. O. box 1171 Blindern 0318 OSLO Norway PHONE. *Department of Pharmacology - Institute of Clinical Medicine.* URL: `https://www.med.uio.no/klinmed/english/about/organization/divisions/laboratory-medicine/pharmacology/index.html` (visited on Nov. 28, 2022).

[44] Mark Marino, Zohaib Jamal, and Patrick M. Zito. *Pharmacodynamics.* Publication Title: StatPearls [Internet]. StatPearls Publishing, Jan. 11, 2022. URL: `https://www.ncbi.nlm.nih.gov/books/NBK507791/` (visited on Nov. 28, 2022).

[45] Sean Grogan and Charles V. Preuss. "Pharmacokinetics." In: *StatPearls.* Treasure Island (FL): StatPearls Publishing, 2022. URL: `http://www.ncbi.nlm.nih.gov/books/NBK557744/` (visited on Nov. 28, 2022).

[46] American Lung Association. *Asthma.* URL: `https://www.lung.org/lung-health-diseases/lung-disease-lookup/asthma` (visited on Nov. 28, 2022).

[47] *Asthma, normal and asthmatic airways, medically illustration Stock Illustration.* Adobe Stock. URL: `https://stock.adobe.com/ie/images/asthma-normal-and-asthmatic-airways-medically-illustration/334995872` (visited on May 25, 2023).

[48] Andrew Bush. "Pathophysiological mechanisms of asthma." In: *Frontiers in pediatrics* 7 (2019), p. 68. URL: `https://www.frontiersin.org/articles/10.3389/fped.2019.00068/full` (visited on Mar. 20, 2023).

[49] Eric Hsu and Tushar Bajaj. "Beta 2 Agonists." In: *StatPearls.* Treasure Island (FL): StatPearls Publishing, 2023. URL: `http://www.ncbi.nlm.nih.gov/books/NBK542249/` (visited on May 24, 2023).

[50] René Aalbers, Claus Vogelmeier, and Piotr Kuna. "Achieving asthma control with ICS/LABA: A review of strategies for asthma management and prevention." In: *Respiratory Medicine* 111 (Feb. 2016), pp. 1–7. ISSN: 09546111. DOI: `10.1016/j.rmed.2015.11.002`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0954611115300834` (visited on May 24, 2023).

[51] Sandeep Sharma, Muhammad F. Hashmi, and Rebanta K. Chakraborty. "Asthma Medications." In: *StatPearls.* Treasure Island (FL): StatPearls Publishing, 2023. URL: `http://www.ncbi.nlm.nih.gov/books/NBK531455/` (visited on May 24, 2023).

[52] Lara Marques and Nuno Vale. “Salbutamol in the Management of Asthma: A Review.” In: *International Journal of Molecular Sciences* 23.22 (2022), p. 14207. URL: `https://www.mdpi.com/1422-0067/23/22/14207` (visited on Mar. 20, 2023).

[53] Peter J. Barnes. “Inhaled Corticosteroids.” In: *Pharmaceuticals* 3.3 (Mar. 8, 2010), pp. 514–540. ISSN: 1424-8247. DOI: `10.3390/ph3030514`. URL: `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4033967/` (visited on May 24, 2023).

[54] Robert Newton and Mark A Giembycz. “Understanding how long-acting 2-adrenoceptor agonists enhance the clinical efficacy of inhaled corticosteroids in asthma – an update.” In: *British Journal of Pharmacology* 173.24 (2016), pp. 3405–3430. ISSN: 1476-5381. DOI: `10.1111/bph.13628`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1111/bph.13628` (visited on May 24, 2023).

[55] *Asthmatic woman using an asthma inhaler during asthma attacks Stock Photo.* Adobe Stock. URL: `https://stock.adobe.com/ie/images/asthmatic-woman-using-an-asthma-inhaler-during-asthma-attacks/271251705` (visited on May 25, 2023).

[56] *nebulizer aerosol woman inhaler machine medicine at home Stock Photo.* Adobe Stock. URL: `https://stock.adobe.com/ie/images/nebulizer-aerosol-woman-inhaler-machine-medicine-at-home/198355289` (visited on May 25, 2023).

[57] Michael J. Coghlan et al. “A novel antiinflammatory maintains glucocorticoid efficacy with reduced side effects.” In: *Molecular Endocrinology (Baltimore, Md.)* 17.5 (May 2003), pp. 860–869. ISSN: 0888-8809. DOI: `10.1210/me.2002-0355`.

[58] *Virtual reality — Definition, Development, Technology, Examples, & Facts — Britannica.* URL: `https://www.britannica.com/technology/virtual-reality` (visited on Nov. 28, 2022).

[59] Jeremy Bailenson. *Experience on Demand: What Virtual Reality Is, How It Works, and What It Can Do.* Google-Books-ID: 2fkqDwAAQBAJ. W. W. Norton & Company, Jan. 30, 2018. 202 pp. ISBN: 978-0-393-25370-2.

[60] *Student Engineer Wearing Virtual Reality Headset Holding Joysticks and Controlling Bionic Limb While Actions Displayed on Screen. Modern Equipment and Computer Science Education in University Concept. Stock Photo.* Adobe Stock. URL: `https://stock.adobe.com/ie/images/student-engineer-wearing-virtual-reality-headset-holding-joysticks-and-controlling-bionic-limb-while-actions-displayed-on-screen-modern-equipment-and-computer-science-education-in-university-concept/521021303` (visited on May 25, 2023).

[61] C. Machover and S.E. Tice. “Virtual reality.” In: *IEEE Computer Graphics and Applications* 14.1 (Jan. 1994). Conference Name: IEEE Computer Graphics and Applications, pp. 15–16. ISSN: 1558-1756. DOI: `10.1109/38.250913`.

[62] Stanley G. (Stanley Grauman) Weinbaum. *Pygmalion’s Spectacles.* Last Modified: 2023-04-10T13:50:30.397733+00:00. URL: `https://www.gutenberg.org/ebooks/22893/pg22893-images.html.utf8` (visited on Apr. 19, 2023).

[63] Carolina Cruz-Neira, Marcos Fernández, and Cristina Portalés. “Virtual Reality and Games.” In: *Multimodal Technologies and Interaction* 2.1

(Feb. 26, 2018), p. 8. ISSN: 2414-4088. DOI: `10.3390/mti2010008`. URL: `http://www.mdpi.com/2414-4088/2/1/8` (visited on Apr. 19, 2023).

[64] *Virtual reality - Education and training — Britannica.* URL: `https://www.britannica.com/technology/virtual-reality/Education-and-training` (visited on Apr. 19, 2023).

[65] Pietro Cipresso et al. "The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature." In: *Frontiers in Psychology* 9 (Nov. 6, 2018), p. 2086. ISSN: 1664-1078. DOI: `10.3389/fpsyg.2018.02086`. URL: `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6232426/` (visited on May 25, 2023).

[66] *Facebook to Acquire Oculus.* Meta. Mar. 25, 2014. URL: `https://about.fb.com/news/2014/03/facebook-to-acquire-oculus/` (visited on Apr. 19, 2023).

[67] *Introducing Project Morpheus.* PlayStation.Blog. Section: PlayStation VR. Mar. 18, 2014. URL: `https://blog.playstation.com/2014/03/18/introducing-project-morpheus/` (visited on Apr. 19, 2023).

[68] *Gear VR: How Samsung makes Virtual Reality a Reality.* URL: `https://news.samsung.com/global/gear-vr-how-samsung-makes-virtual-reality-a-reality` (visited on Apr. 19, 2023).

[69] *Meta Quest 2: våre nye og mest avanserte alt-i-ett-VR-briller — Oculus.* URL: `https://www.meta.com/no/quest/products/quest-2/tech-specs/` (visited on May 24, 2023).

[70] Polona Caserman et al. "Real-time body tracking in virtual reality using a Vive tracker." In: *Virtual Reality* 23.2 (June 1, 2019), pp. 155–168. ISSN: 1434-9957. DOI: `10.1007/s10055-018-0374-z`. URL: `https://doi.org/10.1007/s10055-018-0374-z` (visited on May 24, 2023).

[71] Diederick C. Niehorster, Li Li, and Markus Lappe. "The Accuracy and Precision of Position and Orientation Tracking in the HTC Vive Virtual Reality System for Scientific Research." In: *i-Perception* 8.3 (May 18, 2017), p. 2041669517708205. ISSN: 2041-6695. DOI: `10.1177/2041669517708205`. URL: `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5439658/` (visited on May 24, 2023).

[72] M Papaefthymiou et al. "Mobile Virtual Reality featuring a six degrees of freedom interaction paradigm in a virtual museum application." In: ().

[73] Yang Li et al. "Gesture interaction in virtual reality." In: *Virtual Reality & Intelligent Hardware* 1.1 (Feb. 1, 2019), pp. 84–112. ISSN: 2096-5796. DOI: `10.3724/SP.J.2096-5796.2018.0006`. URL: `https://www.sciencedirect.com/science/article/pii/S2096579619300075` (visited on May 24, 2023).

[74] Jaeyeon Lee et al. "TORC: A Virtual Reality Controller for In-Hand High-Dexterity Finger Interaction." In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* CHI '19: CHI Conference on Human Factors in Computing Systems. Glasgow Scotland Uk: ACM, May 2, 2019, pp. 1–13. ISBN: 978-1-4503-5970-2. DOI: `10.1145/3290605.3300301`. URL: `https://dl.acm.org/doi/10.1145/3290605.3300301` (visited on May 24, 2023).

[75] Chaowanan Khundam et al. "A Comparative Study of Interaction Time and Usability of Using Controllers and Hand Tracking in Virtual Reality Training." In: *Informatics* 8.3 (Sept. 2021). Number: 3 Publisher: Mul-

tidisciplinary Digital Publishing Institute, p. 60. ISSN: 2227-9709. DOI: 10.3390/informatics8030060. URL: https://www.mdpi.com/2227-9709/8/3/60 (visited on May 24, 2023).

[76] *VIVE Pro 2 - The Best VR Headset in the Metaverse — United States.* URL: https://www.vive.com/us/product/vive-pro2/overview/ (visited on May 24, 2023).

[77] *High-Resolution Virtual and Mixed Reality Products.* Varjo.com. URL: https://varjo.com/products/ (visited on May 24, 2023).

[78] *Pimax 8KX DMAS — Pimax.* URL: https://pimax.com/product/vision-8k-x/ (visited on May 24, 2023).

[79] Polona Caserman et al. "Quality criteria for serious games: Serious part, game part, and balance." In: *JMIR serious games* 8.3 (2020). Place: Toronto Publisher: JMIR Publications, e19037–e19037. ISSN: 2291-9279. DOI: 10.2196/19037.

[80] Mayra Carrion et al. "A participatory methodology for the design of serious games in the educational environment." In: vol. 2018-. Book Title: 2017 Congreso Internacional de Innovacion y Tendencias en Ingenieria (CONIITI). IEEE, 2017, pp. 1–6. ISBN: 978-1-5386-0624-7. DOI: 10.1109/CONIITI.2017.8273363. URL: https://ieeexplore.ieee.org/document/8273363 (visited on May 24, 2023).

[81] Marc-André Maheu-Cadotte et al. "Differentiating the Design Principles of Virtual Simulations and Serious Games to Enhance Nurses' Clinical Reasoning." In: *Clinical Simulation in Nursing* 49 (Dec. 2020), pp. 19–23. ISSN: 18761399. DOI: 10.1016/j.ecns.2020.04.004. URL: https://linkinghub.elsevier.com/retrieve/pii/S1876139920300359 (visited on May 24, 2023).

[82] Marco Gesi. *Serious Games and Mixed Reality Applications for Healthcare.* In collab. with Sara Condino et al. MDPI - Multidisciplinary Digital Publishing Institute, 2022. 184 pp.

[83] Carlos Vaz de Carvalho. *Game-Based Learning, Gamification in Education and Serious Games.* In collab. with Antonio Coelho, Carlos Vaz de Carvalho, and Antonio Coelho. Basel: MDPI - Multidisciplinary Digital Publishing Institute, 2022. 182 pp.

[84] Minhua Ma and Andreas Oikonomou. *Serious Games and Edutainment Applications: Volume II.* 1st ed. 2017. Cham: Springer International Publishing : Imprint: Springer, 2017. 1 online resource (XX, 702 p. 181 illu, 122 illu in color.) ISBN: 978-3-319-51645-5.

[85] *Godot Engine.* URL: https://godotengine.org/. (accessed: 27.11.2022).

[86] *Unity.* URL: https://unity.com/. (accessed: 27.11.2022).

[87] *What is Unity? Everything you need to know.* Android Authority. Mar. 20, 2021. URL: https://www.androidauthority.com/what-is-unity-1131558/ (visited on Nov. 28, 2022).

[88] *Cross-platform game engine, Game development software Stock Vector.* Adobe Stock. URL: https://stock.adobe.com/ie/images/cross-platform-game-engine-game-development-software/534209989 (visited on May 25, 2023).

[89] *Unreal Engine.* URL: https://www.unrealengine.com/. (accessed: 27.11.2022).

[90] *Unity vs Unreal Engine.* URL: https://hackr.io/blog/unity-vs-unreal-engine. (accessed: 27.11.2022).

[91] *3D Models for Professionals :: TurboSquid*. URL: `https://www.turbosquid.com/` (visited on May 24, 2023).

[92] Briony J. Oates. *Researching information systems and computing*. London: Sage Publications, 2006. XVII, 341. ISBN: 978-1-4129-0223-6.

[93] Jan vom Brocke, Alan R. Hevner, and Alexander Maedche. *Design science research: cases*. 1st ed. 2020. Progress in IS. Cham, Switzerland: Springer, 2020. 1 online resource (VIII, 319 p. 89 illu, 44 illu in color.) ISBN: 978-3-030-46781-4.

[94] The Australian National University et al. "Positioning and Presenting Design Science Research for Maximum Impact." In: *MIS Quarterly* 37.2 (Feb. 2, 2013), pp. 337–355. ISSN: 02767783, 21629730. DOI: `10.25300/MISQ/2013/37.2.01`. URL: `https://misq.org/positioning-and-presenting-design-science-research-for-maximum-impact.html` (visited on Apr. 14, 2023).

[95] Ken Peffers et al. "A Design Science Research Methodology for Information Systems Research." In: *Journal of Management Information Systems* 24.3 (Dec. 2007), pp. 45–77. ISSN: 0742-1222, 1557-928X. DOI: `10.2753/MIS0742-1222240302`. URL: `https://www.tandfonline.com/doi/full/10.2753/MIS0742-1222240302` (visited on Apr. 14, 2023).

[96] Christian Sonnenberg and Jan vom Brocke. "Evaluations in the Science of the Artificial – Reconsidering the Build-Evaluate Pattern in Design Science Research." In: *Design Science Research in Information Systems. Advances in Theory and Practice*. Ed. by Ken Peffers, Marcus Rothenberger, and Bill Kuechler. Red. by David Hutchison et al. Vol. 7286. Series Title: Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 381–397. ISBN: 978-3-642-29862-2 978-3-642-29863-9. DOI: `10.1007/978-3-642-29863-9_28`. URL: `http://link.springer.com/10.1007/978-3-642-29863-9_28` (visited on Apr. 14, 2023).

[97] David Jones and Shirley Gregor. "The Anatomy of a Design Theory." In: *Journal of the Association for Information Systems* 8.5 (May 1, 2007). ISSN: 1536-9323. DOI: `10.17705/1jais.00129`. URL: `https://aisel.aisnet.org/jais/vol8/iss5/19`.

[98] Anna-Karin Carstensen and Jonte Bernhard. "Design science research – a powerful tool for improving methods in engineering education research." In: *European Journal of Engineering Education* 44.1 (Mar. 4, 2019), pp. 85–102. ISSN: 0304-3797. DOI: `10.1080/03043797.2018.1498459`. URL: `https://doi.org/10.1080/03043797.2018.1498459` (visited on Apr. 24, 2023).

[99] Samir Chatterjee, Kaushik Dutta, and Rangaraja P. Sundarraj. "Utilizing, Producing, and Contributing Design Knowledge in DSR Projects." In: *Designing for a Digital and Globalized World*. Vol. 10844. Lecture Notes in Computer Science. ISSN: 0302-9743. Switzerland: Springer International Publishing AG, 2018, pp. 82–97. ISBN: 978-3-319-91799-3. DOI: `10.1007/978-3-319-91800-6_6`.

[100] Alan R Hevner et al. "Design Science in Information Systems Research." In: ().

[101] Juhani Iivari. "A paradigmatic analysis of information systems as a design science." In: *Scandinavian Journal of Information Systems* 19 (Jan. 1, 2007), p. 39.

[102] Alan R Hevner. "A Three Cycle View of Design Science Research." In: 19 (2007).

[103] Alan R Hevner et al. "Design Science in Information Systems Research." In: ().

[104] Christian Fischer, Robert Winter, and Felix Wortmann. "Design Theory." In: *Business & Information Systems Engineering* 2.6 (Dec. 1, 2010), pp. 387–390. ISSN: 1867-0202. DOI: `10.1007/s12599-010-0128-2`. URL: `https://doi.org/10.1007/s12599-010-0128-2` (visited on Apr. 24, 2023).

[105] Herbert A. Simon. *The sciences of the artificial*. 3rd ed. Cambridge, Mass: MIT Press, 1996. XIV, 231. ISBN: 978-0-262-69191-8.

[106] Petri Kettunen. "Adopting key lessons from agile manufacturing to agile software product development—A comparative study." In: *Technovation* 29.6 (2009). Place: AMSTERDAM Publisher: Elsevier Ltd, pp. 408–422. ISSN: 0166-4972. DOI: `10.1016/j.technovation.2008.10.003`.

[107] Marco A. Boschetti et al. "A Lagrangian heuristic for sprint planning in agile software development." In: *Computers & operations research* 43.1 (2014). Place: OXFORD Publisher: Elsevier Ltd, pp. 116–128. ISSN: 0305-0548. DOI: `10.1016/j.cor.2013.09.007`.

[108] L. Williams and A. Cockburn. "Agile software development: it's about feedback and change." In: *Computer* 36.6 (June 2003), pp. 39–43. ISSN: 0018-9162. DOI: `10.1109/MC.2003.1204373`. URL: `http://ieeexplore.ieee.org/document/1204373/` (visited on May 26, 2023).

[109] *Agile lifecycle development. Stock Vector*. Adobe Stock. URL: `https://stock.adobe.com/ie/images/agile-lifecycle-development/371497302` (visited on May 25, 2023).

[110] T. George (Tegan George). *Mixed Methods Research — Definition, Guide Examples*. Dec. 2, 2022. URL: `https://www.scribbr.com/methodology/mixed-methods-research/` (visited on May 2, 2023).

[111] John Brooke et al. "SUS-A quick and dirty usability scale." In: *Usability evaluation in industry* 189.194 (1996), pp. 4–7.

[112] Aaron Bangor, Philip T. Kortum, and James T. Miller. "An Empirical Evaluation of the System Usability Scale." In: *International Journal of Human-Computer Interaction* 24.6 (July 29, 2008), pp. 574–594. ISSN: 1044-7318, 1532-7590. DOI: `10.1080/10447310802205776`. URL: `http://www.tandfonline.com/doi/abs/10.1080/10447310802205776` (visited on Apr. 11, 2023).

[113] Thomas Tullis and Jacqueline Stetson. "A Comparison of Questionnaires for Assessing Website Usability." In: (June 27, 2006).

[114] *The System Usability Scale: Past, Present, and Future*. ISSN: 1044-7318. URL: `https://www.tandfonline.com/doi/epdf/10.1080/10447318.2018.1455307?needAccess=true&role=button` (visited on May 26, 2023).

[115] Mandy R. Drew, Brooke Falcone, and Wendy L. Baccus. "What Does the System Usability Scale (SUS) Measure?" In: *Design, User Experience, and Usability: Theory and Practice*. Ed. by Aaron Marcus and Wentao Wang. Lecture Notes in Computer Science. Cham: Springer International Publishing, 2018, pp. 356–366. ISBN: 978-3-319-91797-9. DOI: `10.1007/978-3-319-91797-9_25`.

[116] *Questionnaire Stock Photo*. Adobe Stock. URL: https://stock.adobe.com/ie/images/questionnaire/386640058 (visited on May 25, 2023).

[117] Robert Peterson. *Constructing Effective Questionnaires*. Thousand Oaks: SAGE Publications, Inc, 2000. ISBN: 978-0-7619-1641-3. DOI: 10.4135/9781483349022.

[118] *Google Skjemaer: kostnadsfritt og nettbasert skjemaverktøy — Google Workspace*. URL: https://www.facebook.com/GoogleDocs/ (visited on Apr. 28, 2023).

[119] *OpenXR Plugin — OpenXR Plugin — 1.6.0*. URL: https://docs.unity3d.com/Packages/com.unity.xr.openxr@1.6/manual/index.html (visited on May 31, 2023).

[120] *XR Interaction Toolkit — XR Interaction Toolkit — 2.3.2*. URL: https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@2.3/manual/index.html (visited on May 31, 2023).

[121] Barret Zimmerman and Donna Williams. "Lung Sounds." In: *StatPearls*. Treasure Island (FL): StatPearls Publishing, 2023. URL: http://www.ncbi.nlm.nih.gov/books/NBK537253/ (visited on May 25, 2023).

[122] *Breath sounds: MedlinePlus Medical Encyclopedia*. URL: https://medlineplus.gov/ency/article/007535.htm (visited on May 25, 2023).

[123] Unity Technologies. *Unity - Manual: Trail Renderer component*. URL: https://docs.unity3d.com/Manual/class-TrailRenderer.html (visited on Apr. 21, 2023).

[124] *Bézier Path Creator — Utilities Tools — Unity Asset Store*. URL: https://assetstore.unity.com/packages/tools/utilities/b-zier-path-creator-136082 (visited on Apr. 21, 2023).

[125] *Unity - Scripting API: AudioClip*. URL: https://docs.unity3d.com/ScriptReference/AudioClip.html (visited on Apr. 28, 2023).

[126] Unity Technologies. *Unity - Scripting API: Mathf.Lerp*. URL: https://docs.unity3d.com/ScriptReference/Mathf.Lerp.html (visited on May 31, 2023).

[127] Unity Technologies. *Unity - Scripting API: AnimationClip*. URL: https://docs.unity3d.com/ScriptReference/AnimationClip.html (visited on May 31, 2023).

[128] Unity Technologies. *Unity - Manual: Animator Controller*. URL: https://docs.unity3d.com/Manual/class-AnimatorController.html (visited on May 31, 2023).

[129] *Zibra Liquids Pro - Free Trial (subscription) — Physics — Unity Asset Store*. URL: https://assetstore.unity.com/packages/tools/physics/zibra-liquids-pro-free-trial-subscription-244461 (visited on May 2, 2023).

[130] Cleveland Clinic. *Bronchodilator*. Accessed: 2023-05-24. 2023. URL: https://my.clevelandclinic.org/health/treatments/17575-bronchodilator.

[131] T.T Knudsen (Thomas Toft Knudsen). *A practical guide to SUS*. Feb. 18, 2019. URL: https://uxdesign.cc/a-practical-guide-to-sus-9f41a2cb5a55 (visited on May 10, 2023).

[132] Maria Kozhevnikov and Andre Garcia. "Visual-Spatial Learning and Training in Collaborative Design in Virtual Environments." In: *Collaborative Design in Virtual Environments*. Ed. by Xiangyu Wang and Jerry Jen-Hung Tsai. Intelligent Systems, Control and Automation: Science and Engineering. Dordrecht: Springer Netherlands, 2011, pp. 17–26. ISBN:

978-94-007-0605-7. DOI: `10.1007/978-94-007-0605-7_2`. URL: `https://doi.org/10.1007/978-94-007-0605-7_2` (visited on May 29, 2023).