Development and Usability Evaluation of a Virtual Reality Application for Exploring University Labs

Radu Stamatoiu, Silviu Vert, Radu Vasiu
Communications Department, Politehnica University of Timisoara, Romania
Bd. Vasile Pârvan no. 2, Timisoara, Romania
radu.stamatoiu@student.upt.ro, silviu.vert@upt.ro, radu.vasiu@upt.ro

ABSTRACT

Although virtual reality (VR) was initially created as an entertainment medium way back over 70 years ago, it has developed beyond its scope and we are now using it for many other purposes, like education, training and medicine. When it comes to an amazing VR experience, what glues everything together is the level of interactivity and the usability of the application itself. In this paper, we describe a mix of in-person and remote usability testing sessions, with analytics and questionnaires, that we performed to evaluate an educational VR application which was built for Politehnica University of Timisoara (Romania). We conclude with some general feedback and insights that might help other researchers and practitioners in improving similar applications.

Author Keywords
Virtual reality; usability testing; educational application.

ACM Classification Keywords
CCS Concepts: Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Virtual reality

CCS Concepts: Human-centered computing → Human computer interaction (HCI) → HCI design and evaluation methods → Usability testing

DOI: 10.37789/rochi.2021.1.1.24

INTRODUCTION

Along the years, there have been many attempts to have a widely used definition for what VR really is. While none of them can be labelled as wrong, some can feel too generic, so instead of saying that VR is "basically a three-dimensional representation of an environment that's not real, mainly due to computer-generated simulation" [10], we think a better way would be to say that VR is "the sum of the hardware and software systems that seek to perfect an all-inclusive, immersive, sensory illusion of being present in another environment" [3].

In the next chapters, we will describe how we used usability testing in order to understand how users interact within the virtual world and how other researchers tackled this subject. Usability represents a qualitative attribute which can reflect how easy or efficient people can learn to use a system [9]. It is crucial to understand what can be improved, and where users can have difficulties while using a VR application, because when it comes to the immersivity, usability testing can demonstrate that we are able to either make or break the user's dive into the imaginary environment. For the testing sessions, the VR UPT Labs app was used, an application developed this year.

It is dedicated to those who want to learn more about some of the projects that take place at the Politehnica University of Timisoara (UPT) in Romania and familiarize themselves with it by experimenting in a unique way, which lets users visit some of the laboratories through Virtual Reality. The way we interact in the virtual world, and how intuitive the interactions are, represent very important aspects of a successful application. Therefore, those details must be studied through experimentation, because while for an experienced user, moving and interacting in VR might seem easy and intuitive, for someone who never experienced this medium it can be slightly harder to figure out how everything works.

RELATED WORK

Further in this chapter we want to take a brief look over some of the most notable papers that we studied in order to answer some of the questions we had ourselves regarding usability testing for Virtual Reality.

Starting with "Evaluating the usability of Virtual Reality user interfaces" [11] which although quite old by today's standards (published in 2000), feels like it managed, even back then, to incapsulate some of the most important aspects of the user interfaces' usability in VR. In this paper, the author even goes as far as to create a lists of questions that developers and creators should ask themselves in order to mitigate as many of the potential usability problems as possible. We are positive that going through this and making sure all the tasks and questions mentioned by Mr. Sutcliffe are satisfied, any VR application is on the right path when it comes to ensuring high usability.

"A multi-site study examining the usability of a virtual reality game designed to improve retention of sterile catheterization skills in nursing students" [5] is a study that uses a System Usability Scale (SUS) questionnaire in order to establish a rating for the application they created. This study is important because hundreds of people took part in it and the authors describe an application designed to help nursing students to improve their skills when it comes to sterile catheterization. Therefore, similarily to ours, this application is not necessarily for general use purposes, yet that should not stop it from being accessible to anyone.

A more sensitive study is represented in the paper "Usability Testing of an Interactive Virtual Reality Distraction Intervention to Reduce Procedural Pain in Children and Adolescents With Cancer" [4] which describes an application dedicated to distract children (with ages between 8 and 18 years old) who suffer from cancer in order to make it easier for the medical to finish needle procedures. The paper goes over the multiple iterations done in order to improve the VR app, which can offer useful insights into what to look for when it comes to developing a personal application on our own.

"3D User Interface Design and Usability for Immersive VR" [7] and "Interactive UI Design for VR" [6] are two other works that debate how user interfaces should work in virtual reality and from which we learned about diegetic and non-diegetic UI, which we will elaborate on in a future chapter.

Going through all these papers helped us to get a better understanding on how crucial usability testing is. After all, these applications were always developed for all the people around, not just one single person (the creator). However, despite all the effort put into them, each had their own degree of personal research due to the nature of the apps developed. And by this, we mean that each used different usability testing methods to suit their needs, which is why we had to conduct this process ourselves and try to pick what worked the best and try to improve upon it. One example in which we did this is by using heatmaps, which were not the main concern in any of the papers mentioned in this chapter.

DEVELOPMENT OF THE VR APPLICATION

The VR UPT Labs application is developed in Unity and is part of a more ample project which should help people learn more about the Politehnica University of Timișoara and technology in general. Unity is a cross-platform real-time engine, mainly used for video games, but definitely not limited to them since many simulations, augmented reality applications, virtual reality applications, and other type of applications are made using this capable engine [12]. The reason we picked Unity is because it is wildely used, well documented, flexible and offers support for VR applications out of the box, as long as the integration of the Oculus Rift (which is the virtual reality headset used during the development) module is done properly. Another important factor is the fact that Unity has many built-in functions which allow designers to develop complex code, create 3D environments and implement real-time 3D or 2D animations. The models can be created, rigged and animated in any 3D computer graphics toolset, and then imported to Unity, which will allow scripting on top of them as well.

The code for the project is all written in C#. Other examples of software that was used while working on the project are Blender, OpenStreetMap and OSM2World.

Blender has been used for creating basic 3D models (which only took a few hours with the whole learning process), OpenStreetMap to extract certain geographical data which was later converted in a 3D model using OSM2World. This whole process of extracting and creating the layout of the university took around one hour in which small modifications were done to the cropping process. The application layout contains a few rooms, one of which is the main hub (Figure 1).

Figure 1. Screenshot of the main hub of the VR UPT Labs app.

From this so-called hub zone, the users can either go explore 3D recreations of real-life laboratories, where they can learn and find some of the projects that take place in those labs, or they can decide to see 360° scans of other rooms, hallways and parts of the university. A simplified block scheme is presented in Figure 2.

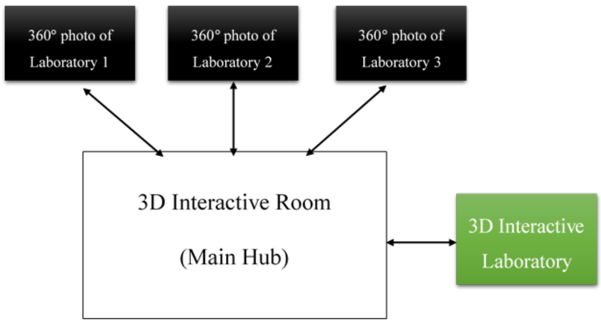

Figure 2. Simplified layout of the application.

In the 3D interactive laboratory, the users have complete freedom upon what they can do. After going through Alistair G. Sutcliffe's paper [11] it was our decision to let them explore and find out the way they can interact with different objects. The author defined this type of freedom as exploratory browsing, in which the user's sole purpose is to explore the system for the sake of curiosity. Although there is no specific goal, "various objects may need to be investigated and remembered for future reference" [11]. In this way, some subtle hints were added in order to highlight specific interactions that can occur, but the user has to recognize them and sometimes even figure them out on his own.

The 360° rooms are less impressive and they are a fast way of exploring bits of the university in ways similar to Google StreetView. In the version of the application that the usability testing has been done for, those scenes did not provide any kind of information, which is a subject for a future iteration.

Although the development has been done entirely on a PC with an Oculus Rift S connected, three of the participants have used their personal headsets and confirmed that the application works on Oculus Quest 1 and 2 (which are the standalone versions of the headset), running natively or from a personal computer. Because VR UPT Labs is built using the XR Interactive Toolkit framework, it should work with any kind of VR headset, as long as it was properly set up. However, we did not get the chance to try them all out (except the Oculus Rift, Oculus Rift S and both versions of Oculus Quest) so we cannot guarantee that the experience will be the desired one when using, for example, the HTC Vive or Valve Index (which are two other well-known VR headsets).

The UI (user interface) is entirely diegetic, meaning that no piece of information, be it buttons or texts are displayed in a separate layer on top of the view of the user (like it is done in most of the applications which contain a pause menu, for example, that pops on top of the main screen) [6]. More exactly, the whole UI exists within the virtual world and it is not something only displayed for the player. It can be ignored and passed through or interacted with, almost like a physical object present in the scene, and if multiple users would use the application at once. Figure 3 will showcase an example of instructions displayed in the virtual reality application.

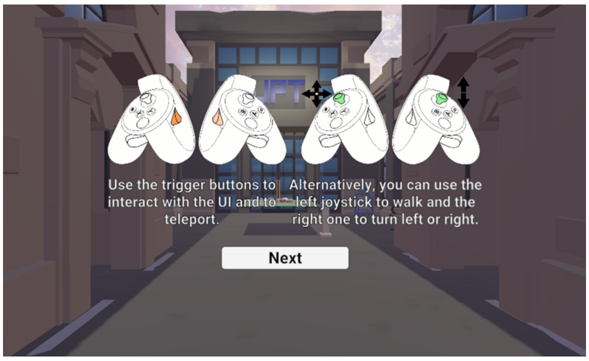

Figure 3. Diegetic UI, existing in the virtual world as part of it.

The controls are simple and explained in the very first moment the user is dropped into the virtual world because in the past, while developing another VR application, this was one of the main complaints of the participants: that they could not figure out how to use the app without proper guidance offered externally. Only two buttons and a joystick for each hand are needed to operate everything.

The goal was to have at least 5 different interactions in a virtual laboratory in order to offer a decent amount of interactivity for the end users. Some of them were writing on a whiteboard, opening drawers, putting on a pair of headphones, playing with a hexapod robot and so on. An example of an interaction can be seen in figure 4 where the user uses a tablet to rate the application inside the virtual world.

Figure 4. Interaction with a tablet in virtual reality.

EVALUATION OF THE VR APPLICATION

In order to evaluate the usability of the virtual reality application we have performed 3 different testing methods. We would have rather done only in-person user testing sessions, but due to the different restrictions imposed nowadays because of the Covid lockdowns, we had to resort to remote testing as well. Most of the participants agreed to be recorded during the sessions. In total, 8 participants took part in the testing procedures, 5 of which did it remotely and 3 in person. They were aged between 16 and 50 years old, mostly males (only two of them being females). They were recruited based on their availability to be volunteers in this experiment and based on their previous experience with similar applications. This took place in June 2021. All of them were given a SUS questionnaire at the end of the experience to evaluate it. We decided to pick the System Usability Scale quiz because it can provide a fast but reliable enough way of ranking the usability [8]. Further down we will elaborate on each one of them with a brief description of how the testing went, and the results will be the subject of the following chapter.

A. Collecting analytics and data during the testing sessions

This method involves collecting data like time spent on a task in the app, crash reports, heatmaps, where people look, and how frequent do they change their position. It is pretty much invisible to the end user because it is done only so the developer can have access to this data after a testing session. It is always useful to document findings even if they might seem unrelated. When it comes to more complex or very specific applications, it can be also useful collecting heart beat rate, blood pressure, etc.

Heatmaps have been studied since the 19th century. They represent a data visualization technique that aims to represent certain areas in which specific actions take place (for example where a user spends more time exploring) using colors [14]. Although Unity has support for heatmaps, it is not offered in the free version of the engine, therefore we had to develop a more basic and rudimentary internal system that would help us keep track of where the users spend most of the time when using the application. This solution worked by having multiple invisible zones delimited around the room which would constantly track the time spent by the user inside them. The visualization of the data was done in an image editing software in order to smoothen out the shapes and make it easier to be analyzed. In figure 5 it can be noticed that, most of the times, the participants were interacting in the right part of the room.

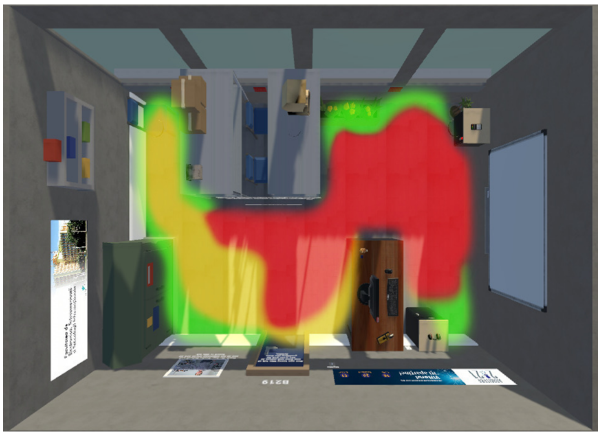

Figure 5. Heatmap of the robotics lab.

Aside from the heatmaps, what was also tracked was the time until the user would voluntarily decide to stop using the application, and how long would they spend watching two different videos presenting creations which could be found in the laboratory. A crash log was also by default put in place, but luckily no crashes were experienced in any of the sessions.

B. In-person user testing

Some experts, like the ones over at VR Oxygen claim that this type of testing is "probably the most productive and the most challenging user testing method" [13]. Which we agree, especially due to the fact that despite the extra preparation needed in order to conduct this testing (preparing the environment and setup), it offers the possibility to see the participant's reactions and body language as well. One simple example that we have seen happening during the usability testing was that although at some point one of the users was feeling pretty nauseous, he claimed that he feels fine. This could have been quite misleading if the testing would have happened remotely, because the dead giveaway that the participant was not feeling perfectly was the lightheaded way of moving with the headset on. Obviously, some users are tempted to hide the way they feel because they do not want to be embarrassed.

This testing method had 3 people arrive at our location in different days and try out the application. The recording of the screen was done using a free open source tool called OpenBroadcaster[12] and some of them were also recorded using a smartphone, so we can re-watch and analyze again the footage for information that we might have missed. Notes were taken and they were let to explore the application on their own with no tasks involved. Prior to jumping in the virtual world, they were only told to explore on their own and to interact with anything they feel like.

Figure 6. Photo of the in-person testing session.

Throughout the whole testing session, the participants were encouraged to speak out their thoughts, because usually the best thing that comes to mind might be the most sincere and it would represent valuable feedback. It is also important to be as impartial as possible and explain to the users that there is no such thing as harmful or bad feedback [2]. Sometimes they might tend to try and avoid being sincere to not hurt the facilitator's feelings which can be slightly misleading because it will not highlight some flaws in the application. Because of this, as a general suggestion, it is good to have new people in each testing session who can offer a fresh view on the project as well as be less emotionally involved.

Obviously, is very important for the tests to be consistent. The evaluator must make sure that everyone is testing the same version or the same part of the application to avoid discrepancy between the participants' experiences.

C. Remote user testing

As mentioned in the introduction, because of certain restrictions in the last few months, 5 of the participants had to realize the testing remotely. Obviously, the biggest disadvantage to this method is what makes the in-person one the best: the fact that the user is not in the same room and environment as the observer. However, this comes packed

[12] OpenBroadcaster is available at: https://obsproject.com/

with a few advantages as well, like the fact that the participants will be testing in a familiar environment where they can feel more comfortable. This way the feedback can also be more honest and less influenced by the organized session which can feel a bit artificial for some. It also helps that this way the testing can scale up more and involve different genders, ages, nationalities and so on.

The remote testing sessions were done through Discord[13], which is a free social platform which supports voice, video and screen sharing calls. Each participant had to use their own setup and devices, therefore two different types of virtual reality headsets were used in this case (the Oculus Quest 1 and Oculus Quest 2).

Figure 7. Photo taken during the remote testing.

Due to the nature of this testing, all participants were experienced users, since they needed to own VR headsets, which affected the evaluation of the application. They were more keen to rate more positively the application because they already knew how to work in a virtual world. This aspect slightly helped the SUS questionnaire score to be a little bit higher. Even so, the feedback was consistent and valuable. Because this is a quite easy to set up test, it is recommended that it should be done from very early stages of development. Repeated periodically with each new milestone achieved with the project, it will provide constant fresh and valuable feedback, especially if new participants take place in the process. The session data was captured and recorded during the remote testing as well.

D. The SUS questionnaire

In order to have consistent metrics while testing, all participants completed the System Usability Scale [8] quiz at the end of the testing session. This type of questionnaire can be applied to a variety of products, hardware or software. It is made up of 10 items, each with 5 possible answers ranging from strongly disagree to strongly agree. Here, we replaced the term "system" with the term "VR application".

1. I think that I would like to use this VR application frequently.
2. I found the VR application unnecessarily complex.
3. I thought the VR application was easy to use.
4. I think that I would need the support of a technical person to be able to use this VR application.
5. I found the various functions in this VR application were well integrated.
6. I thought there was too much inconsistency in this VR application.
7. I would imagine that most people would learn to use this VR application very quickly.
8. I found the VR application very cumbersome to use.
9. I felt very confident using the VR application.
10. I needed to learn a lot of things before I could get going with this VR application.

This way, the final result is a number between 0 and 100 which can represent the score of the application. Furthermore, we used the SUS scoring methodology [8] used in order to attribute an adjective to the final score (Worst Imaginable – Awful – Poor – OK – Good – Excellent – Best Imaginable) [1], which was 72.5, representing a 'Good' rating.

All users had a free field below the questionnaire in which they could provide any kind of additional feedback in case it wasn't mentioned during the testing session itself.

USABILITY TESTING RESULTS AND DISCUSSION

From a quantitative point of view, the data recorded from the sessions provided the most amount of information, but the in-person testing sessions and the remote ones offered important details related to the quality of the application itself. Therefore, we will split up the results in quantitative and qualitative ones.

A. Quantitative results

In order to have an overview of the results that can be quantified, we will look at the data obtained from the session recording. The average time that users spent in the application without being forced to be or spend extra time is 7 minutes and 12 seconds. Of course, in our situation, user retention is not a priority and the application is not intended to do so. Compared to studies such as "3D User Interface Design and Usability for Immersive VR" [7], we can draw the erroneous conclusion that a user spends 7 times more time on average in the educational application. Of course, this is wrong because in the case of the aforementioned study, only the speed of fulfilling some very specific tasks is tested.

Through the heatmap we could also deduce that over 75% of the time, users will spend it in the right part of the robotics virtual lab. This happens because most of the interactions take place in that area. We could conclude in this case a need to develop interactions in the left half of the laboratory to balance and encourage more exploration throughout the scene. It is

[13] Discord is available at: https://discord.com/

difficult to assess whether in just over 7 minutes users have time to accumulate the information provided by the application, especially considering that the informative parts, are offered through videos of about 5 minutes, which were almost completely ignored. Therefore, perhaps in the next version a new method should be tried in order to be able to increase the time spent assimilating information.

Knowing that the SUS average score obtained was 72.5, we tried to compare it to the ones obtained in other studies. The score is 15.5 units higher than the one obtained in the paper related to the application for training medical staff to cauterize various wounds [5]. But here are important factors that can be used to justify the results in both papers. Firstly, it is the number of users who took part in the test (300 in the case of the medical application and only 8 in the case of the educational application), and secondly, the percentage of them who represent the target audience. Thus, taking into account that 5 of the people who participated in our usability study had contact with virtual reality prior to this experience, the score is slightly influenced by them. In the next test session, the division into two groups of experienced and inexperienced users will be done in order to be able to delimit and compare the averages obtained from their feedbacks to the SUS questionnaires. Obviously, there are many aspects that can be improved and that have been mentioned in the comments section of the questionnaire, which we will go over further.

B. Qualitative results

The biggest disadvantage signaled by completing the SUS questionnaires was that users would not use the application very often. This does not mean, however, that it is not desired, but only that it is suitable for a specific environment and has no high reusability. Based on the feedback, we can even see this from one of the users. Participant 1 mentioned in the comments section the following remark: “it is not that I do not like, but the fact that once I have explored and seen all the laboratories, I will not return to them too soon, knowing everything in them”. Therefore, perhaps a way to vary the interactions in each laboratory should still be considered, or a post-development plan should be established, through which new updates should be made in the application.

Next, we will go over some of the main observations during the tests. Like the mention in the paper "Evaluating the usability of virtual reality user interfaces" [11], the test helped to discover some problems in the area of interactivity and how it can take place. For example, a cube left on the desk that aimed to trigger an animation of the robotic arm when it was put in the right place. Most users mentioned that they did not know exactly where it should be placed, because it was not highlighted in any way. Of course, watching the educational clip, which presents the robotic arm, would have shown this detail and probably suggested to users what they can use the cube for. But since no one had the patience to watch the whole film, they failed to figure out what needed to be done for the interaction to take place and admired the static object. This made us reconsider all the interactions which require perquisite knowledge in order to be triggered. After this feedback, measures were taken to improve and highlight the place where the cube is missing, as can be seen in figure 8. Also, the cube will be colored once it is brought close enough to the robotic arm, in order to let the user know that they are placing it in the right location.

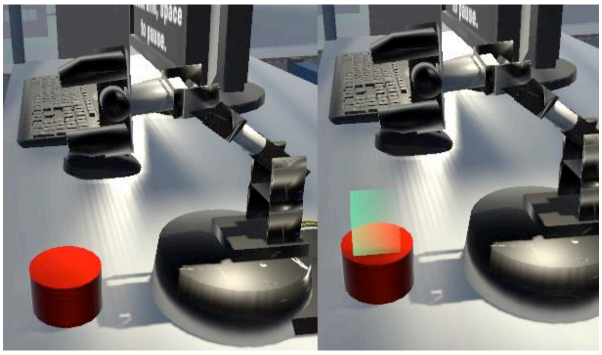

Figure 8. Subtle change done to highlight a missing object in order to trigger an interaction once placed accordingly.

Similarly, one user complained that when the lights are on, this aspect is not visible enough and he can practically not tell if the switch is doing something. Problems of this kind are highlighted even by question 8 in the work of Alistair G. Sutcliffe [11] which refers to the very consequences of user action and whether they are visible or not. It has been shown to us that a variety of people, with various jobs, who test the application can bring pleasant surprises. For example, another observation by the same participant highlights the following: “Usually, switches turn on a light bulb when they are lowered. I know this because I am an electrician by profession, and it was one of the first strange things I noticed”. This aspect was not mentioned by any other person and went completely unnoticed even by me, although naturally and instinctively, we should have thought of the real scenario to avoid the small problem.

Participant 4 complained about the slow speed he has when he chooses to move by using the joystick, without teleporting (figure 9). As a solution, work is currently underway to implement a speed adjustment option to accommodate as wide a range of users as possible, both experienced and novice. It should be noted, though, that high speed can induce a feeling of nausea, so we initially opted for a lower speed that accommodates beginners.

Figure 9. Screenshot which shows one of the locomotion modes, the teleportation.

One more example of comment during the testing, this time from participant 6, was: "Your interaction with the hexapod should be highlighted because it is not easy to figure out. And it is not mentioned anywhere", which is why an indicator (which disappears after the first use) now appears on the hexapod, suggesting that you can interact with it, in order to turn it on (figure 10). "There is no music or background sound", with the verbal addition that it should be heard constantly. An aspect that is also in the works, but with a lower priority, because there is the possibility to use headphones in order to listen to some music while using the application.

Figure 10. The change done to the hexapod robot in order to highlight the fact that it's interactable.

OVERALL DISCUSSION AND CONCLUSIONS

The result of this project is a virtual reality application, on which usability testing is performed periodically, in a continuous development and available on several platforms. It aims to allow and facilitate as efficiently as possible users to dive into a virtual world to learn more about the faculties, get acquainted with various laboratories and explore the Politehnica University of Timisoara. This application could also be an excellent tool for helping people learn about technology, find out more about the university and the projects that take place inside it, having a solid development base and being decently documented due to the tools used (Unity, XR Interaction Toolkit, Oculus, etc.). Digitalizing the university is something that has not been fully considered by many higher education institutions, let alone the ones in Romania. We consider that this paper could be valuable for anyone who plans on creating any kind of VR application because it highlights more general usability issues that can happen during the development cycle. It can also be considered an example of why usability testing is quite crucial for VR apps and reflects on our experience with different types of testing. Unlike the studies referenced, in this case elements like heatmaps were also used, which are missing from many other works. They are widely underestimated and could potentially save time further down the line, knowing where the users spend their time looking and moving. Sometimes avoiding a complete removal of a component or functionality, as it happened in medical app designed for the children with cancer [1], where the medical staff complained that they could not properly realize the procedures because the children kept trying to look down in order to check the leaderboard and see their score against other competitors. This ended up with the developers having to remove the leaderboard completely, which took time to be developed in the first place.

Some notable general observations are: the fact that users do not look around is not a reprehensible thing, nor does it directly reflect the quality of the application, but only that people in general need to be guided because they are not yet fully accustomed to looking around in a virtual world; they will usually try to interact with any object in a scene; ergonomics and accessibility must be taken into account, no matter how much time users spend with their hands raised or their heads bowed (which can lead to fatigue very quickly). The application should be neither too complex nor too simple, and the only way to find that suitable area between the two is by testing usability repeatedly. The ways in which the testing is performed can be combined, but must be chosen carefully depending on what the developed project involves. Feedback should be as uninhibited as possible, within the limits of common sense, and it would be ideal for participants to be part of the target audience.

As for the future, besides expanding the application itself, we are looking into adding several other functions that aim to increase the accessibility of VR UPT Labs for people with disabilities (possibility to adjust the sound volume, height adjustments, colors adjustments by applying filters according to the type of the color blindness the user suffers from, the option to adjust the controls/button layout for those with missing fingers, and other). In this way we want the application to be fully usable by people in wheelchairs, with various vision/hearing problems, and other disabilities, but this will involve expanding and diversifying the study sample.

REFERENCES

[1] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining what individual SUS scores mean: Adding an adjective rating scale. Journal of usability studies 4, 3 (2009), 114–123.

[2] Carol Barnum. 2020. Usability Testing Essentials: Ready, Set...Test, 2nd ed. (2nd ed.). Morgan Kaufmann. Retrieved from https://www.elsevier.com/books/usability-testing-essentials-ready-set-test/barnum/978-0-12-816942-1

[3] Frank Biocca and Mark R. Levy (Eds.). 1995. Communication in the Age of Virtual Reality (1st edition ed.). Routledge, Hillsdale, N.J.

[4] Kathryn A. Birnie, Yalinie Kulandaivelu, Lindsay Jibb, Petra Hroch, Karyn Positano, Simon Robertson, Fiona Campbell, Oussama Abla, and Jennifer Stinson. 2018. Usability Testing of an Interactive Virtual Reality Distraction Intervention to Reduce Procedural Pain in Children and Adolescents With Cancer. J Pediatr Oncol

Nurs 35, 6 (November 2018), 406–416. DOI:https://doi.org/10.1177/1043454218782138

[5] Karen R. Breitkreuz, Suzan Kardong-Edgren, Gregory E. Gilbert, Connie DeBlieck, Mariam Maske, Christy Hallock, Susan Lanzara, Kathryn Parrish, Kelly Rossler, Carman Turkelson, Anthony Ellertson, Kimberly N. Brown, Taylor Swetavage, Michael Werb, Elizabeth G. Kuchler, Lori S. Saiki, and Shelly R. Noe. 2021. A multi-site study examining the usability of a virtual reality game designed to improve retention of sterile catheterization skills in nursing students. Simulation & Gaming 52, 2 (April 2021), 169–184. DOI:https://doi.org/10.1177/1046878120954891

[6] Jason Pavik. 2020. Interactive UI Design for VR. SMU Guildhall. Retrieved from https://jasonpavik.com/projects/KrrAYx

[7] Hind Kharoub, Mohammed Lataifeh, and Naveed Ahmed. 2019. 3D User Interface Design and Usability for Immersive VR. Applied Sciences 9, 22 (January 2019), 4861. DOI:https://doi.org/10.3390/app9224861

[8] James R. Lewis. 2018. The System Usability Scale: Past, Present, and Future. International Journal of Human–Computer Interaction 34, 7 (2018), 577–590. DOI:https://doi.org/10.1080/10447318.2018.1455307

[9] Jakob Nielsen. 2003. Usability 101: Introduction to usability.

[10] Giovanni Saggio and Manfredo Ferrari. 2012. New trends in virtual reality visualization of 3D scenarios. Virtual Reality-Human Computer Interaction (2012).

[11] A. G. Sutcliffe and K. Deol Kaur. 2000. Evaluating the usability of virtual reality user interfaces. Behaviour & Information Technology 19, 6 (January 2000), 415–426. DOI:https://doi.org/10.1080/014492900750052679

[12] Unity Technologies. Unity Real-Time Development Platform | 3D, 2D VR & AR Engine. Retrieved July 19, 2021 from https://unity.com/

[13] VR Oxygen. User Testing for VR AR Software. Retrieved July 19, 2021 from https://vroxygen.com/

[14] Leland Wilkinson and Michael Friendly. 2009. The History of the Cluster Heat Map. The American Statistician 63, 2 (May 2009), 179–184. DOI:https://doi.org/10.1198/tas.2009.0033