https://doi.org/10.2352/EI.2025.37.13.ERVR-168

ScryVR: A Systematic Framework for Accelerating Experimental Research in VR

Levi Scully, Jose Toro Cerna *, Pengbo Chu**, Frederick C. Harris, Jr.*, Sergiu M. Dascalu;**
Computer Science and Engineering, University of Nevada, Reno, Nevada, USA
****Mining and Metallurgical Engineering; University of Nevada, Reno, Nevada, USA***

Abstract

Virtual Reality (VR) technology has experienced remarkable growth, steadily establishing itself within mainstream consumer markets. This rapid expansion presents exciting opportunities for innovation and application across various fields, from entertainment to education and beyond. However, it also underscores a pressing need for more comprehensive research into user interfaces and human-computer interaction within VR environments. Understanding how users engage with VR systems and how their experiences can be optimized is crucial for further advancing the field and unlocking its full potential. This project introduces ScryVR, an innovative infrastructure designed to simplify and accelerate the development, implementation, and management of user studies in VR. By providing researchers with a robust framework for conducting studies, ScryVR aims to reduce the technical barriers often associated with VR research, such as complex data collection, hardware compatibility, and system integration challenges. Its goal is to empower researchers to focus more on study design and analysis, minimizing the time spent troubleshooting technical issues. By addressing these challenges, ScryVR has the potential to become a pivotal tool for advancing VR research methodologies. Its continued refinement will enable researchers to conduct more reliable and scalable studies, leading to deeper insights into user behavior and interaction within virtual environments. This, in turn, will drive the development of more immersive, intuitive, and impactful VR experiences.

Introduction

Virtual Reality and Augmented Reality have been talked about as products of the future, a lot of this has been down to the size of the problem. It is only recently that hardware advancements have began to accelerate into creating the technology required for achieving the VR/AR future developers are dreaming of. This rapid expansion has highlighted a growing need for more research into user interfaces and human-computer interaction experiences for this form of media. To create a solid foundation from which to solve this growing problem, this assignment looks into well executed VR user studies and VR applications created to help design and facilitate user studies.

The specific interest of VR user study tools and frameworks comes from my interest in ”meta-tools”. In Every Tool’s a Hammer: Life is What You Make It Adam savage describes the two main ideals that combine into his shop philosophy. What might first might look like a mess to another person, he explains, that the visual cacophony of tools and materials displayed in plain sight instead of hidden away in drawers or cabinets allowing his subconscious to be aware of all the potential options open to him. This is augmented with ”First-order Retrievablity”, Adam places any tools that might be needed in multiple places around his shop to minimize interruptions.

These combine into the goal of creating a workspace with the lowest barriers to the flow state possible, where Adam finds he is most productive[13]. Having this shop philosophy allows Adam to understand his relationship to his work and to his work space, this ”meta-tool” lets him design the space to suit his strengths and weaknesses. I think that using support tools like the ones covered is a necessary way to approach work, by focusing and refining on how best to enable oneself to succeed, you might just find the pathway there.

By closely examining the user studies of other VR researchers and analyzing my own experiences administering them, I began to note down the common research walls in my path. This lead me to my research philosophy, provide a research environment that has little to no barriers to research. The pillars I have decided to focus on to achieve that goal are support tools, software and frameworks dedicated to assisting in experimentation processes and analysis tools, robust software approaches to the analysis and refinement of research experimentation.

Background and Related Work

With hardware being the primary limitation, Virtual Reality (VR) has been relegated to the pages of science fiction for the majority of human history. In 1935 American science fiction writer Stanley Wienbaum published his short story ”Pygmalion’s spectacles” where the main character is presented a pair of goggles enabling fully immersive interaction with the world of the story[15]. Ray Bradbury’s short story ”The World the Children Made” released in 1950, featuring a couple whose smart home includes a nursery that provides holographic simulations for their children [3]. Each of these stories went on to inspire a present day form factor of VR, Pygmalion’s spectacles inspired the mixed reality headsets and Bradbury’s influence can be seen in cave style VR approaches.

In 1965 Computer Scientist Ivan Sutherland presented his concept of the Ultimate display. In his words:

> “The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked[14].”

Within three years Sutherland and his Student Bob Sproull created the first virtual reality head mounted display (HMD), named after the mythological Sword of Damocles, the massive device hung from the ceiling and while capable of proving the potential of The Ultimate Display, it was cumbersome and computer graphics were limited to the hardware at the time. In the interceding time we have seen many VR devices from research hardware to failed consumer products, with no real movement until the year 2014 when Facebook purchased the VR start up Oculus and the market decided to start taking VR seriously [2]. It is primarily since this water shed moment that majority of the innovation in the field has taken place.

Research submitted to the Human Computer Interaction Conference CHI in 2020, examined the presentation of pre, and post questionnaire's embedded in the virtual environment and questionnaires taken on computers after participants have removed their headsets and returned to the real environment. The findings stated that both factors of questionnaires had comparable completion times between with users reporting greater enjoyment from the embedded questionnaires [1]. Additionally taking the participant out of the virtual environment before reporting their experience may introduce bias due to the break in presence caused by removal of the VR headset and return to the real environment [10]. To facilitate these findings a Questionnaire toolkit was developed by Feick et. all with the purpose to provide the tools to create and embed custom questionnaires into VR [7].

Continuing on the path of support tools, the Unity Experiment Framework developed by Jack Brookes et al. and several years later StudyVR by Yaojie Li et al. aim at solving the difficulty behavioral scientists encounter when attempting to conduct VR research by providing support software to aid in the design process [4, 9]. This goal is ultimately undercut by both approaches by leaving the primary creation of the experiment left to the user, both approaches require a decent amount of skill in the Unity Game Engine.

By incorporating mixed reality into the equation CReST by Cools et. all incorporate a facilitator role in the user study application, this role experiences a mixed reality experience, with low levels of immersion allowing the facilitator to watch the participant react and interact with the virtual objects in the environment [6].

Another AR approach is MIRIA a Mixed Reality interaction analysis toolkit designed to support the in-situ visual analysis of user interaction in mixed reality. This application overlays participant data over the environment they were tested in, allowing for examination of complex interaction data [5]

As VR headsets become more and more affordable, it becomes more possible and reasonable to design remote VR research frameworks. Conducting remote user studies can be a challenging task, and while the ability to recruit more participants is possible, the very nature of the devices will bias the recruitment pool, additionally the dedicated VR activity space is different for each home and this greatly limits the amount of space available for researchers to use [11, 12]. RemoteLab by Lee et. all offers a toolkit much like the previously mentioned toolkit, along with a video feed setup for their supervised remote user study approach [8].

Using VR applications to analyze and view VR user study data collected from past participants, has been introduced and

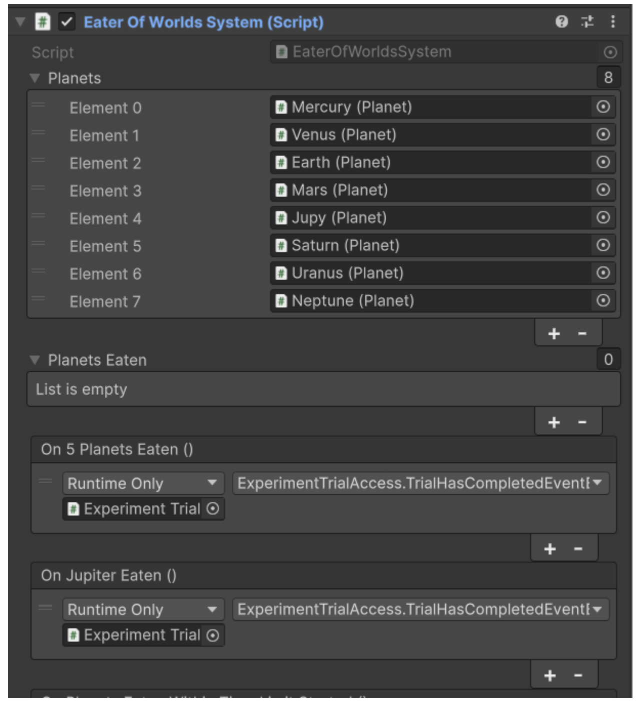

Figure 1. *Unity Inspector Example of Using User Study Custom Events*

there is a vast potential for HCI and data science in VR and AR information visualization. Remote VR user studies are going to be gaining more attention as headsets get cheaper and in more homes across the world. As VR has enabled new AR approaches and technologies we will start to see a lot of research done into the effects of Immersive levels on many aspects of VR research from education to entertainment.

ScryVR Development

ScryVR introduces a methodical, step-based approach supported by tools and automation features that lower barriers to VR and HCI research. It enables experienced VR researchers and developers to conduct investigations more efficiently. The platform includes a starting template built with the Unity game engine, Meta Quest hardware, and the Meta XR Core SDK.

Unlike prior efforts that address isolated pain points but lack comprehensive functionality, ScryVR takes a modular approach. It provides several interconnected systems while maintaining consistent naming conventions to simplify discussions of complex research concepts. In ScryVR, Tasks refer to actions participants perform to test hypotheses, while a Factor represents an independent variable, such as the type of input device (e.g., mouse or trackpad). A Trial is defined as a unique Task attempt associated with a specific Factor. This structured framework offers flexibility and clarity, helping researchers streamline experimentation and focus on broader insights.

User Study System

Utilizing the ScryVR template starts off with defining the independent and dependent variables and what tasks the participant will complete in order to test the hypothesis. Then through a creation wizard script you set the number of tasks and the number of independent variables, then the amount of trials per each combination. The creation wizard then generates a script called ”Threads of Fate” this generates the complex switch statements and a empty function for every task factor combination. These empty functions should be filled in with the set up procedure for a task, present a UI text object, play a audio file, instantiate game objects. Then utilizing the Unity prefab architecture a gameobject called a ExperimentTrialAccess is generated, by dragging the gameobject into a Unity ActionEvent the system is able to register when the trial is completed an example of this can be seen in 1.

The Fates System

The Fates system provides the system to set up the individual tasks, and utilizes the balanced latin squares to order the tasks within each individual session. Utilizing the IEnumerator type the system takes in a trailID and returns the corresponding function to setup the trial. This enables the ability to deliver a different trial order for every participant with a robust scriptable event driven system.

The Questionnaire System

A unity monobehavior for displaying and answering questionnaires in VR or any unity capable platform. The system takes from hard coded survey questions and randomly displays questions to participants. On question answer the system utilizes the REST API to send answer values to the database. When the entire questionnaire is done, a custom event is sent to the User Study System, which then sends a request to the fates system for the next task to display.

Two primary data collection tools provided each collect data, a timer based collection, data is collected every set amount of seconds and a movement based collection, data is collected when the attached game object moves or rotates beyond the set threshold. A MySQL database connection with tables set up already for VR data collection, other potential data pipelines are provided such as a local csv, and a Raw binary file as well. A Rest API was developed as a middle layer for the VR system to pass data into the database.

User Study Development

We expect the proposed experimental research (on a framework aimed at accelerating user studies, which are at the core of experimental research) will confirm the potential of ScryVR as a viable supporting method and tool set for VR and AR applications. To analyze the strengths and weaknesses of ScryVR as supporting software for experimental research, a previously published study by Putze et al (2020) has been chosen and adapted, this time re-designed and conducted using ScryVR [10].

Our hypothesis is that the results will indicate an increase in user satisfaction and presence (the latter, in the sense of ”being there,” in the environment) when participants complete the questionnaire in the virtual environment, thus contributing to the expanding body of VR research and development. To explore this hypothesis, we address the following research questions:

Quantitative Research Questions: How does the immersive virtual reality environment affect task completion time and accuracy when compared to a non-immersive environment? What is the impact of immersion level on users' physiological responses (e.g., heart rate, skin conductance) during task completion?

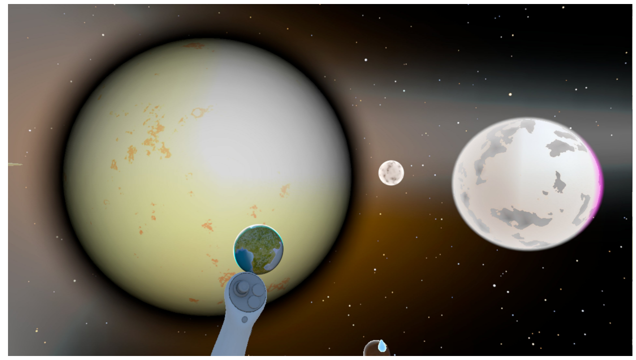

Figure 2. Fully Immersive Virtual Environment

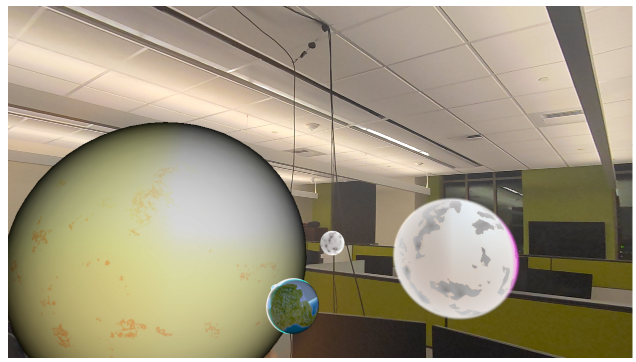

Figure 3. Simulated Pass-through Augmented Reality Environment

Qualitative Research Questions: How do users perceive their sense of presence and engagement in a fully immersive VR environment compared to an augmented reality pass-through experience? What are participants' subjective assessments of usability and comfort when completing tasks in a fully immersive VR environment versus a pass-through AR environment?

Independent Variable(s) and Factors

The first independent variable in our study is the level of immersion, with factors: (i) a fully immersed virtual reality experience, and (ii) a pass-through augmented reality experience. The second independent variable is the environment users are in while completing questionnaires, with factors:(i) inside the virtual environment, or (ii) outside of the virtual environment.

Dependent Variables

Several dependent variables are measured for this user study, specifically time to complete a survey, dynamics of interactivity, and user satisfaction and sense of presence. Related measurements include data collected during a user's participation in answering the survey: number of mouse movements, time taken to complete a survey, number of miss-clicks during the survey, controller and headset movements, and sensor data from an EmotiBit used to compare biometrics between users' experiences. Dependent variables are also assessed based on the qualitative responses obtained from the participants during the post-test (exit) questionnaire.

Figure 4. Questionnaire within immersive virtual environment

Figure 5. Questionnaire outside immersive virtual environment

Apparatus

We used an application developed in Unity Editor version 2022.3.47f1. The application will run on a Meta Quest 3 headset for participants to fully engage in the VR experience. When completing the questionnaires outside of the virtual environment participants will be utilizing a desktop computer running windows.

In addition, an EmotiBit was integrated, an advanced biometric monitoring device that will allow real-time recording of physiological data from participants. EmotiBit will be worn on the participants upper arm and can measure key variables like heart rate, heart rate variability (HRV), skin temperature, skin conductance (indicative of galvanic skin response or GSR), and other factors related to electrodermal activity. This data will capture emotional and stress indicators in participants, offering a deeper perspective on how immersion in the virtual environment affects not only visible behavior but also the emotional and internal physiological state of users.

Participants

The study was conducted with 8 participants, all of whom were students of the Computer Science program at the University of Nevada, Reno (UNR). The participants had moderate familiarity with virtual reality technologies and video games, which enabled them to adapt quickly to the VR environment. The group consisted primarily of men, which may inform considerations for future studies.

Procedure

Participant arrive at research lab and is informed verbally that if at anytime during the experiment the participant feels unsafe or ill that they can remove the headset at anytime and this experiment can end at anytime they feel. After the participant acknowledges understanding they are informed that a once the virtual reality headset is on their head and the experiment application started they will see consent information about the experiment, a print out of this will be available to any participant that requests one. The participant is then given the Pre-Task questionnaire on PC.

The facilitator will then launch the experiment executable, handing the headset to the participant to place on their head, immediately afterward the facilitator will hand them each controller, one for each hand.

The primary structure of the user-study is as follows, A participant is involved in 2 user study sessions with each session consisting of two sets of tasks meant to build engagement, placed in our local solar system the participant is asked to complete 3 tasks presented randomly by ScryVR, (Eat 5 Planets, Eat as many planets as you can in two minutes, and eat Jupiter), after which the participant completes a PENS survey and the Igroup Presence questionnaire presented within the Virtual Environment or outside the Virtual Environment on a nearby computer.

Post-Task Questionnaires

A total of three questionnaires were selected for the study, replicating the same questionnaires utilized by Putze et al. (2020) to gain insights into participants' experiences during the experimental sessions [10]. These questionnaires were carefully chosen to evaluate player engagement, sense of presence, and potential distractions, providing a comprehensive overview of participant responses.

The Player Experience of Needs Satisfaction (PENS) Survey consists of 21 questions divided into five key categories: Competence, Autonomy, Relatedness, Presence/Immersion, and Intuitive Controls. Each category is designed to capture distinct aspects of the participant's gaming experience. Before responding, participants were prompted with the following instruction: "Reflect on your play experiences and rate your agreement with the following statements." This encouraged participants to consider their emotional and cognitive responses during the session, allowing for a more focused evaluation of their experience.

The Igroup Presence Questionnaire (IPQ) is a widely used tool for assessing the sense of presence within a virtual environment. It measures participants' perceived immersion and engagement across four categories: General Presence, Spatial Presence, Involvement, and Experienced Realism. The IPQ provides valuable insights into how deeply participants felt integrated into the virtual environment and how convincingly the environment replicated real-world experiences. This aspect is particularly crucial for understanding how different modalities, such as virtual reality and augmented reality, affect the user's sense of presence.

The Distraction Survey, based on the methodology by Putze et al., included four straightforward questions. Participants were asked to rank the level of distraction caused by various factors: leaving the VR environment, answering the questionnaires, the recording of biosignals, and noise from the external environment. These questions aimed to identify potential disruptions that could affect participant focus and engagement during the study. After completing the final questionnaire, participants were thanked for their time and effort, reinforcing a positive conclusion to their involvement in the study.

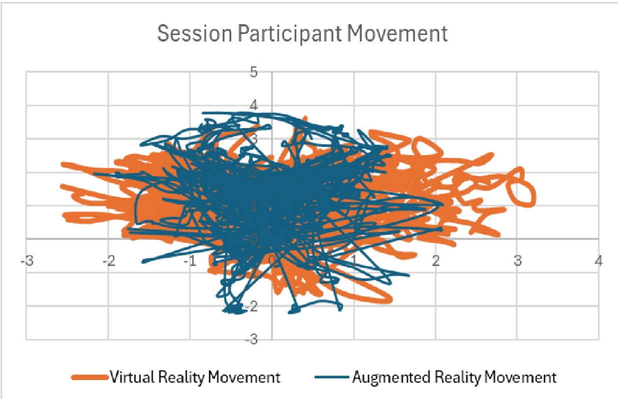

Figure 6. Virtual and Augmented Reality Participant movement

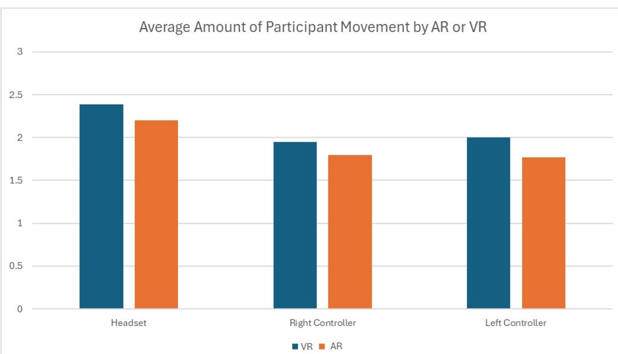

Figure 7. Average amount of device movement in VR and AR

Results and Discussion

In Figure 6, we see a 2D top-down representation of the mapped movements of the participants. This figure provides an overview of movement patterns and highlights outliers in behavior, indicated by distinct colors that are visibly separate from the main cluster of data points. These outliers may represent participants who exhibited unique interactions with the environment or experienced different levels of immersion during the study. On average, participants in the virtual reality (VR) modality moved 3.74 units away from the starting area, whereas participants in the augmented reality (AR) modality moved an average of 1.29 units. Figure 7 visually contrasts these modalities and clearly illustrates that VR participants explored their environment more extensively than AR participants.

The VR group demonstrated significant movement across multiple devices. On average, VR participants walked 2.39 units from the starting position, moved the right controller 1.95 units, and the left controller 1.99 units. In contrast, AR participants showed less movement in all metrics, walking an average of 2.20 units while moving the right controller 1.79 units and the left controller 1.77 units. This pattern suggests that VR participants were more actively engaged with their environment, which could indicate a stronger sense of immersion during the study.

Initially, while facilitating the user study, I had hypothesized that AR participants would exhibit greater movement. This assumption was based on the premise that AR overlays virtual elements onto the physical testing environment, allowing participants to maintain visual contact with their real-world surroundings. This comfort with physical reality was expected to encourage more freedom of movement. However, the data contradicted this assumption. The VR participants, who were fully immersed in a virtual environment, moved more overall.

This suggests that the immersive nature of VR may encourage participants to explore their environment more freely. The heightened sense of presence in VR could motivate users to engage more actively with the virtual world, despite the absence of visible physical boundaries. In contrast, AR participants may have subconsciously restrained their movements due to the simultaneous awareness of their physical surroundings.

Questionnaire Responses

Using the Virtual Reality modality participants ranked 18 questions higher when outside of the Virtual Environment and 13 questions higher inside the virtual environment with 4 being ranked equally between virtual environments. Using the Augmented Reality modality participants ranked 11 questions higher when outside of the Virtual Environment and 16 questions higher inside the virtual environment with 7 being ranked equally between virtual environments. Now when we compare the results of the questionnaires across VR and AR we see no real trend in the way participants answer questions inside a Virtual Environment or Outside a Virtual Environment. This is likely due to the participant count not giving enough self reported data to identify any trends within the dataset.

Task Completion and Accuracy

During the process of synchronizing timestamps between the database and the Emotibit device, a critical bug was identified that severely impacted data alignment with corresponding events. This bug prevented the system from accurately correlating physiological data, such as heart rate and skin conductance, with specific moments or activities during the study. While the Emotibit successfully collected raw data, the inability to synchronize timestamps rendered this data less meaningful. Without proper synchronization, it was impossible to establish connections between the physiological trends observed and the actual occurrences during the study. Consequently, the data, while potentially insightful at a high level, failed to provide the nuanced understanding required for deeper analysis.

Conclusions and Future Work

During the development of the user study, a significant issue was discovered: the MySQL database was not compatible with the Android operating system on the Meta Quest 3. To resolve this, a REST API was developed and hosted on a laptop, using the ngrok framework to establish a connection with the MySQL database. While this approach effectively resolved the compatibility issue and greatly improved application performance by offloading the majority of calculation, it introduced significant complexity and diverted valuable time away from rigorously testing the application's many systems.

Due to these time constraints, several integration issues with the database emerged. Though individually minor, these issues collectively caused critical failures. For example, lag between host systems occasionally led to application freezes, resulting in the loss of multiple participant sessions. These setbacks severely impacted the reliability of the data collected.

From the data that was successfully retrieved, it was not possible to draw definitive conclusions about the impact of the virtual environment on user responses to questionnaires. However, some intriguing trends were observed. Participants in fully immersive environments exhibited increased movement compared to those in pass-through environments. Additionally, device movement data revealed that three participants were left-hand dominant, providing valuable demographic insights.

The ScryVR template performed well in many aspects of the study but faced challenges as the study's complexity increased. Unity, in particular, struggled to handle the study's design, which required managing three separate Unity applications. This limitation introduced additional technical hurdles. The Fates system demonstrated reliable performance throughout the study, excelling in task balancing and event automation. Its ability to streamline study management and ensure smoother execution proved essential. The system provided a consistent framework that kept the study organized and tasks synchronized.

In conclusion, while the study offered meaningful insights, technical challenges such as synchronization issues, database compatibility, and Unity's limitations highlighted areas for improvement. Future iterations should prioritize better error reporting for facilitators, enhancements to the database system for seamless integration and data analysis, and refinements to ScryVR's design to ensure smoother execution and more reliable outcomes. These adjustments will be crucial for advancing the effectiveness of future user studies.

Acknowledgments

This material is based in part upon work supported by the National Science Foundation under grants IIS-2202640. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

[1] Dmitry Alexandrovsky et al. "Examining Design Choices of Questionnaires in VR User Studies". In: *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. CHI '20. Honolulu, HI, USA: Association for Computing Machinery, 2020, pp. 1–21.

[2] Dom Barnard. *History of VR – timeline of events and Tech Development*. July 2024.

[3] Ray Bradbury. *The illustrated man: Short stories*. Doubleday, 1951.

[4] Jack Brookes et al. "Studying human behavior with virtual reality: The Unity Experiment Framework". In: *Behavior Research Methods* 52 (Apr. 2019).

[5] Wolfgang Büschel, Anke Lehmann, and Raimund Dachselt. "MIRIA: A Mixed Reality Toolkit for the In-Situ Visualization and Analysis of Spatio-Temporal Interaction Data". In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. CHI '21. Yokohama, Japan: Association for Computing Machinery, 2021.

[6] Robbe Cools, Xuesong Zhang, and Adalberto L. Simeone. "CReST: Design and Evaluation of the Cross-Reality Study Tool". In: *Proceedings of the 22nd International Conference on Mobile and Ubiquitous Multimedia*. MUM '23. Vienna, Austria: Association for Computing Machinery, 2023, pp. 409–419.

[7] Martin Feick et al. "The Virtual Reality Questionnaire Toolkit". In: *Adjunct Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. UIST '20 Adjunct. Virtual Event, USA: Association for Computing Machinery, 2020, pp. 68–69.

[8] Jaewook Lee et al. "RemoteLab: A VR Remote Study Toolkit". In: *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*. UIST '22. Bend, OR, USA: Association for Computing Machinery, 2022.

[9] Yaojie Li and Andrew Hogue. "StudyVR: A Framework for Streamlining VR User Study Design". In: *2024 IEEE Gaming, Entertainment, and Media Conference (GEM)*. 2024, pp. 1–5.

[10] Susanne Putze et al. "Breaking The Experience: Effects of Questionnaires in VR User Studies". In: *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. CHI '20. Honolulu, HI, USA: Association for Computing Machinery, 2020, pp. 1–15.

[11] Rivu Radiah et al. "Remote VR Studies: A Framework for Running Virtual Reality Studies Remotely Via Participant-Owned HMDs". In: *ACM Trans. Comput.-Hum. Interact.* 28.6 (Nov. 2021).

[12] Radiah Rivu et al. "'Can you Set It Up On Your Own?' – Investigating Users' Ability To Participate in Remote-Based Virtual Reality Studies". In: *Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia*. MUM '22. Lisbon, Portugal: Association for Computing Machinery, 2022, pp. 121–127.

[13] Adam Savage. *Every tool's A hammer: Life is what you make it*. London, England: Simon & Schuster, 2019.

[14] Ivan E. Sutherland. "The Ultimate Display". In: 1965.

[15] Stanley G. (Stanley Grauman) Weinbaum. *Pygmalion's spectacles*. Dec. 2024.

Author Biography

Levi Scully, a Master's student in Computer Science and Engineering, specializes in Human-Computer Interaction (HCI) and Mixed Reality. They earned their Bachelor's degree in 2024 from the University of Nevada, Reno, where they led the development of Eureka!, a VR mining education experience. As a graduate student, Levi focuses on advancing HCI infrastructure, mentoring undergraduate teams, and driving collaborative research to enhance tools and methodologies.