Summary

Virtual reality (VR) is becoming increasingly accessible with developments in technology, making headsets and software development more common to meet education and training needs. Virtual reality experiences (VRE) are intended to give the viewer a realistic experience inside a virtual world, using the technologies to influence the human brain into believing that what they are experiencing is real, allowing the impact of the VRE to be that of a seemingly real experience.

This report will provide an overview of the components of VR which are critical to the experience of the viewer. Some of these components, such as the Head Mounted Display (HMD), can provide various degrees of immersiveness depending on the quality of the hardware used (various models are discussed with more information).

Benefits to using VR as a training modality is that are can allow the user to access environments that may not always be immediately feasible and provide an experience that can effectively teach skill and transfer knowledge, according to research discussed in this report. Some challenges are that, while the market for VR technology is quickly developing and driving prices down for equipment like headsets, the cost for producing VR, purchasing the appropriate equipment, and providing any ongoing maintenance for the software and/or hardware, could still be cost prohibitive for some. There are a variety of options to choose from when developing VREs and it is important to consider the effectiveness and cost of the chosen platform when developing it.

Information will be provided that discusses several VR labs in the United States focused on the development and utilization of VR, including one lab located locally at the University of California, San Diego. Other labs include those at UC Berkeley, Texas State, University of Montevallo, and Stanford University. Three of the labs are located within Social Work programs and several have a sociological and/or psychological basis for their projects. Additionally, information will be provided that discusses VR for social work and/or child protection through Deloitte and the University of Kent as examples of VR in non-lab settings.

Lastly, the report concludes with research studies that evaluate the effectiveness of VR as a training modality and its ability to transfer learning in education settings more effectively than traditional methods. Studies show that using VR to train users to adapt skills and knowledge is more effective than classroom training, and can be impacted by the immersiveness of the VRE.

The appendices of this report include implications for creating content, user design, and configuring hardware to present the best user experience, critical to the user being able to effectively learn the material presented to them in the VRE.

Background on Virtual Reality

Virtual reality (VR), is a realistic three-dimensional image or artificial environment created using interactive hardware and software. The user of VR interacts with this environment in a seemingly real or physical way.

Key Elements of a VR Experience[1]

1. *Virtual World*- The content of experience should be dictated by what the intention is for the learner. Instructional designers creating the virtual world should be cognizant of how the environment is guiding the user's experience.
2. *Immersion*- The perception of being present in a non-physical world that allows the human brain to believe it is somewhere it is not. Total immersion happens when enough of the senses believe the person is present in the non-physical world. Two common types of immersion:
    a. Mental Immersion- deep mental state of engagement with suspension of disbelief that one is in a virtual environment.
    b. Physical Immersion- physical engagement in a virtual environment with suspension of disbelief that one is in a virtual environment.
3. *Sensory Feedback*- VR requires as many senses as possible to be stimulated through sensory feedback, which involves a mixture of hardware and software to achieve.
4. *Interactivity*- It is crucial that the ability to interact with the virtual world is quickly responsive for the participant to continue to feel immersed and natural in the environment. Delays in the ability to interact in the virtual environment can be disruptive to the learner.

Common Types of Virtual Reality

- *Non-Immersive*: Only a subset of the participant's senses are engaged and there is peripheral awareness of the reality outside of the VR simulation.
- *Semi-Immersive*: This type of simulation and technology are commonly found in flight simulation training and while not fully immersive, still tend to focus on the visual immersion of the user.
- *Full-Immersive*: This type commonly involved head-mounted displays and motion detecting systems to stimulate all of the participant's senses.

Components of a Virtual Reality System

- PC/Console/Smartphone
- Head-Mounted Display (HMD)

[1] The Ultimate Guide to Virtual Reality (VR) Technology. *Reality Technologies*. Retrieved from http://www.realitytechnologies.com/virtual-reality

- Common HMD hardware:
  - High price point and does not use a cell phone: HTC Vive, Oculus Rift, Sony Playstation VR.
  - Lower price point ($100 or less), and does use specific cell phones: Samsung Gear VR, Google Daydream View, Google Cardboard, Merge VR Goggles.
  - There are also several headsets available at retail stores and online for under $20 (with some as low as $2.99). While these are much more affordable, the immersive experience may be changed with the type of hardware, and thus the learning experience of the user may also be influenced.

- Input Devices
  - Common input devices that add to the user's experience of convincing the human brain that they are present in the VR environment:
    - Joysticks
    - Force Balls/Tracking Balls
    - Controller Wands
    - Data Gloves
    - Trackpads
    - On-Device Control Buttons
    - Motion Trackers/Bodysuits
    - Treadmills
    - Motion Platforms

Virtual Reality Labs/Projects

VR labs around the country are being created to explore the usage of virtual worlds in a variety of fields. The following summarizes outline labs that bring VR learning to classrooms, social science settings, and explore the effect of VR on various aspects of human cognition.

A. University of California, San Diego (UCSD)- Virtual Reality Lab[2]

- In May 2017, UCSD opened its new teaching and research laboratory for undergraduate students to develop content for VREs. The lab has 25 Oculus Rift HMDs, VR controllers, computer workstations, 360-degree cameras, hand tracking devices and an HTC Vive system.

[2] Ramsey, D. (May 30, 2017). UC San Diego opens first virtual reality lab for undergrads. University of California. Retrieved from https://www.universityofcalifornia.edu/news/uc-san-diego-opens-first-virtual-reality-lab-undergrads

- The lab mostly serves students taking courses in software programming for augmented and virtual reality (AR/VR). This lab is the first of its kind in the country to teach undergraduate students this type of technology.
- Virtual Reality Club at UCSD[3]
  - The VR Club is a student organization that connect members with the VR industry through workshops, projects, and networking. Their mission is, "to foster a multidisciplinary community dedicated to exploring and creating Virtual and Augmented Reality experiences."

B. University of California, Berkeley, College of Engineering- Center for Augmented Condition, Immerex VR Lab[4]

- This lab is is currently in development.
- This lab will support, "Berkeley students and faculty in their research on human cognition modeling, human-computer interaction and human-robot collaboration through augmented and virtual reality technologies."
- This lab is funded by Immerex, a Bay Area-based company specializing in VR technologies.

C. Texas State School of Social Work- Virtual Reality Technology Lab[5]

- A fully-immersive VR environment that trains in the following areas using Oculus Rift (industry leader in headset hardware) and Unity (common open source game development engine):
  - Radiation Therapy Stimulation for clinicians to use linac radiation therapy equipment in a virtual setting, allowing for trainees to see the internal organs and skeleton structure of the patient which is not possible in more traditional training modalities.
  - Distracted Driving Simulation involves creating an environment for the user to experience first hand the negative effects of using a smartphone while driving. From this study, 70% of participants reported an increased awareness of the dangers of using their smartphones while driving and/or reported using their smartphones less while driving.
  - Addiction Treatment VR involved cue exposure and cue extinction treatment where patients can be exposed to cues that may trigger a relapse, yet they are in a safe and controlled environment. This can empower the individual to manage their response if/when they later encounter these triggers in everyday life.

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[3] Virtual Reality Club at UCSD. Retrieved from http://vrclub.ucsd.edu/

[4] Rhodes, K. March 14, 2017. Gift from virtual reality pioneer Immerex will create AR/VR lab at Berkeley. Berkeley Engineering. Retrieved from http://engineering.berkeley.edu/2017/03/gift-virtual-reality-pioneer-immerex-will-create-arvr-lab-berkeley

[5] Virtual Reality Technology Lab. Texas State School of Social Work. Retrieved from http://www.socialwork.txstate.edu/centers-institutes/VRTL.html

D. University of Montevallo, Alabama- VR for Group Dynamics[6]

- Still in the development stage, the bachelor's degree in Social Work (BSW) program is implementing a virtual reality experience using the HTC Vive (HMD).
- This VR is part of the *Social Work with Small Groups* class and involves fully immersing the student in an environment that looks like a classroom with four seated virtual clients/avatars in front of the student. The student selects a client/avatar, with whom they will interact, engaging with pre-recorded dialogue full of descriptions of issues the client/avatar is having that day. The student can interact with the clients/avatars by asking them to hear more about what they were saying, interrupt and move on, or suggest other steps to move their goals forward.
- Eventually, this VR will also include the ability to guide the student through the group therapy session, challenging the student to make more decisions regarding leadership of the group, and will give the student a grade at the end for their performance. Additional features to be added to the simulation include having a client/avatar react highly emotionally by yelling at the student, and having the student read the non-verbal communication cues of a client within the simulation. The last layer of development will involve using a motion capture rig called a Perception Neuron suit so that someone can act out the body language of an avatar in the simulation.

E. Virtual Human Interaction Lab- Stanford University

- The mission of the Virtual Human Interaction Lab at Stanford University is to understand the dynamics and implications of interactions among people in immersive virtual reality simulations, and other forms of human digital representations in media, communication systems, and games.
- The research projects of the lab tend to fall under one of three larger questions:
  - What new social issues arise from the use of immersive VR communication systems?
  - How can VR be used as a basic research tool to study the nuances of face-to-face interaction?
  - How can VR be applied to improve everyday life, such as conservation, empathy, and communications systems?
- Current projects:
  - *Examining Racism with VR*: Immersive VR allows a user to viscerally embody an avatar who encounters racism.
  - *Childhood Development and Immersion*: This project is working on researching the effects of non-immersion and immersion VR and the social and physiological reactions that children have to the characters/avatars. This is adding to their

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[6] Beal, B. (2017). Teaching Group Dynamics Using Virtual Reality. *The New Social Worker.* Retrieved from http://www.socialworker.com/feature-articles/technology-articles/teaching-group-dynamics-using-virtual-reality/

growing body of research looking at the effect of immersive virtual environments on children.
    - *Empathy at Scale*: VR simulations allow learners to experience life from another person's point of view in order to teach empathy. This research is building on previously limited research by expanding their sample size to include 100 demographically diverse participants in a variety of empathy scenarios.
    - *Sustainable Behaviors*: This consists of two VR projects that aim to teach people about the effect of climate change in marine environments.
    - *Immersion and Presence*: This project will build off of a meta-analysis examining how immersive is enough, by looking at the spatial, social, and learning effects through manipulation of the VR's Field of View, Image Persistence, Update Rate, Latency, and Tracking Level.
    - *Learning in Immersive VR*: This project is investigating the interactions between class subject, learning environment, and classroom makeup on participants along with interest and learning in a virtual class.
    - *Homuncular Flexibility*: This project examines the user's ability to control an avatar within the VRE and how that contributes to their sense of presence, increased immersion or increased learning.

F. Deloitte- GoCase Virtual Reality Application

- Deloitte has developed a VR application that allows social workers to assess the danger and safety factors inside of a family's home.
- The social worker uses a headset to experience the application, while their supervisor guides the worker using a checklist to ensure the worker accurately assesses the items inside the house.
    - The headset being used for this application is the lower-end, lower-cost hardware (priced at $13-$20).
- GoCase VR is currently being piloted with a Louisiana child welfare agency and will be available for purchase by other jurisdictions soon.

G. University of Kent- Centre for Child Protection, Child Protection Simulations[7],[8]

- These simulations are computer-based games that put workers in various child welfare scenarios to be used as training tools for social workers. Each of the simulations require specific computer requirements, come with their own set of Learning Outcomes, and have training instructions for those administering the game. Each simulation can be purchased by an individual or an organization by contacting the department directly.
- The following simulation games have been developed:
  - *Rosie 1*- This introductory course is free to download and use. It involves going into Rosie's house and interacting with the family. It includes discussion points and a follow up video for social workers.
  - *Rosie 2*- This game builds off of what the social worker has learned about the family from Rosie 1 and gives the learner more discussion and skill building in their interaction with different family members. This game is not free but can be purchased by individuals and organizations.
  - *MyCourtroom*- This interactive and immersive simulation continues the story of Rosie, taking place inside of a courtroom and building on skills and knowledge social workers may need when working with families in the court system.
  - *Looking out for Lottie*- This simulation revolves around recognizing the behaviors of an unhealthy relationship and grooming patterns for those at risk of child sexual exploitation.
  - *Zak*- This simulation game focuses on the risks of online and social media influence in regards to terrorism, grooming, and child sexual exploitation.
  - *Maryam and Joe: Behind Closed Doors*- This simulation game also focuses on the influence of social media and its effect on young people in regards to grooming for terrorism, extremism, and child sexual exploitation. It uses mock social media platforms to train workers on online behaviors of those who target young people.
  - *Visiting Elliot*- This simulation puts workers in the home of a sex offender recently released to home and trains workers on recognizing risk factors in his life.

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[7] Note: The University of Kent is located in the United Kingdom and its practices and policies are based on those specific to the agencies in the UK. It is included in this report due the innovative approach it has taken in immersive child welfare training.

[8] *Child Protection Simulations.* The Centre for Child Protection. University of Kent. Retrieved from https://www.kent.ac.uk/sspssr/ccp/simulationsindex.html

Research Studies on Virtual Reality as a Training Modality

VR has served as a training tool in many fields, bringing realistic experiences closer to the user in order to teach skills and knowledge for use in professional and educational settings. Studies have captured VR's ability to transfer learning to the user and compare it to that of traditional learning modalities like classroom learning. Below are key highlights from various studies in different fields. Note that these research summaries are not exhaustive of all VR research, as this modality has been used across a wide variety of professional and educational fields.

A. A Pilot Feasibility Study of Virtual Patient Simulation to Enhance Social Work Students' Brief Mental Health Assessment Skills[9]

- Standard simulations are used in the training settings of different fields (nursing, medicine, psychology), utilizing real people to act as patients or clients for trainees to practice with and learn from, developing their skills in a low-risk environment.
- Studies have found that utilizing simulation-based environments for training is more effective than traditional clinical education in regards to skill acquisition. Simulations, while reliable and valid, can be labor intensive and cost prohibitive, while VREs are able to address some of those limitations.
- VR for training clinicians has evolved into being capable of creating avatars with an authenticity of credible appearances and behaviors. They can be programmed to respond to body language, tone of voice, and facial expressions.
- Mechanisms being researched that can make VR an effective training tool are interactivity, ease of navigation, and ability to accurately depict clinical scenarios. It also must somehow integrate timely and appropriate feedback to support skill acquisition.
- Research has shown that training using VR have equivalent outcomes to using simulations and trainees rated them as equally effective.[10]
- *Key Findings:* Virtual practice simulations in this study were associated with an increase in diagnostic accuracy and improvement in overall brief assessment skills. Some limitations of the study included frustrations from the learner about the accuracy of the voice recognition software and suggestions were made to continually update software to align with new developing technologies (can be costly), and an option to use text-based interactions rather than voice.

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[9] Washburn, M., Bordnick, P., & Rizzo, AS. (2016). A pilot feasibility study of virtual patient simulation to enhance social work students' brief mental health assessment skills. *Social Work Health Car*e. 55(9), 675-693. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/27552646

[10] Botezatu, M., Hult, H., Tessma, M. K., & Fors, U. (2010). Virtual patient simulation for learning and assessment: Superior results in comparison with regular course exams. *Medical Teacher*, 32, 845–850. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20854161

Cook, D. A., Hatala, R., Brydges, R., Zendejas, B., Szostek, J. H., Wang, A. T., Erwin P.J., & Hamstra, S. J. (2011). Technology-enhanced simulation for health professions education. *JAMA: the Journal of the American Medical Association*, 306, 978–988. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/21900138

- Note: This study did not have a control group and thus, there are limitations to its findings. However, it was the first of its kind to evaluate a virtual learning environment with MSW students, and the results can serve as preliminary support for continued research.

B. Virtual Patient Simulation: Knowledge Gain or Knowledge Loss?[11]

- *Study Overview:* This was a randomized controlled study on early and delayed assessment results of 49 students using Virtual Patients (VPs) for learning and examination of hematology and cardiology topics in an internal medicine course.
- The study participants were assigned to either a study group utilizing a computer-based software program on hematology and cardiology, or a control group utilizing traditional learning methods which included lecture, small-group assignments, and discussions. Assessments were given to both groups using an online platform taught to both the study and control groups. The study group also used this platform to access their VPs.
- *Key Findings:* For hematology topics, there was a moderate loss of knowledge in delayed examinations with the VR group (compared to a significant loss of knowledge in delayed examinations with traditional methods), with grades of students superior in the VR group compared to the control group. Cardiology results for the study group showed a small gain in delayed examination using the online VR platform and no or small gain in regular exams. The grades of the study group in regards to cardiology topics were again higher for the study group.
- Recommendations from this study in regards to retention of knowledge is that VPs should be used for spaced education with periodic testing that utilizes open-ended questions for assessment and opportunities to continue to practice knowledge and apply skills.

C. Virtual Reality Training Improves Operating Room Performance: Results of a Randomized, Double-Blinded Study[12]

- *Study Overview:* Sixteen surgical residents participated in the study. They were assessed at baseline for psychomotor abilities (no differences were found between the control and study groups). They were split between a VR trained group and a controlled, non-VR trained group.
- *Key Findings:* Gallbladder dissection was 29% faster for VR trained residents. Non-VR trained residents were 9 times more likely to fail to make progress and 5 times more

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[11] Botezatu, M., Hult, H., Tessma, M. K., & Fors, U. (2010). Virtual patient simulation: Knowledge gain or knowledge loss?. *Medical Teacher*, *32*(7), 562-568. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20653378

[12] Seymour, N. E., Gallagher, A. G., Roman, S. A., O'Brien, M. K., Bansal, V. K., Andersen, D. K., & Satava, R. M. (2002). Virtual Reality Training Improves Operating Room Performance: Results of a Randomized, Double-Blinded Study. *Annals of Surgery*, *236*(4), 458–464.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1422600/

likely to injure the gallbladder to surrounding tissue. Mean errors were six time less likely to occur in the VR trained group.

D. Feasibility of Using an Augmented Immersive Virtual Reality Learning Environment to Enhance Music Conducting Skills[13]

- *Study Overview:* The implementation of VREs was studied in regards to enhancing the skills of beginning wind band conductors. Areas studied were nonverbal conducting skills of eye contact, torso movement, and gesture of novice band conductors who have completed at least one course in conducting. A contact control group and two VRE experimental groups participated in pretest/posttest conducting of a live ensemble with eight intervening treatment sessions.
- *Key Findings*: Gain scores from pretest to posttest measures of eye contact, torso movement, and gesture were higher for participants who practiced their conducting using an augmented VRE with head tracking as compared to those who practiced their conducting using traditional techniques or in an augmented VRE without head tracking. The largest gains in this study were from those learners who were provided with the greatest sense of reality through the virtual learning environment.

E. Technology-Enhanced Simulation for Health Professions Education: A Systematic Review and Meta-analysis[14]

- *Study Overview:* From a pool of 10,903 articles, 609 eligible studies were identified, totalling 35,226 trainees. Of these, 137 were randomized studies, 67 were nonrandomized studies with two or more groups, and 405 used a single-group pretest-posttest design.This meta-analysis used the definition of Stimulation Technologies to include diverse products including computer-based virtual reality simulators, high-fidelity and static mannequins, plastic models, live animals, inert animal products, and human cadavers.
- *Key Findings*: With rare exceptions, technology-enhanced simulations were associated with better learning outcomes compared to no intervention or when added to traditional practice. There was a high inconsistency in regards to the magnitude of association for individual studies, reflecting variation of modes, clinical topics, learner groups, instructional designs, research methods, and outcome measures.

[13] Orman, E. Price, H., & Russell, C. (2017) Feasibility of using an augmented immersive virtual reality learning environment to enhance music conducting skills. Journal of Music Teacher Education. 27(1), 24-35 Retrieved from http://journals.sagepub.com/doi/pdf/10.1177/1057083717697962

[14] Cook D.A., Hatala R., Brydges R., Zendejas B., Szostek J.H., Wang A.T., Erwin P.J., & Hamstra S.J. Technology-Enhanced Simulation for Health Professions Education: A Systematic Review and Meta-analysis. *JAMA*.2011;306(9):978–988 Retrieved from https://jamanetwork-com.libproxy.sdsu.edu/journals/jama/fullarticle/1104300

F. Effectiveness of Virtual Reality-based Instruction on Students' Learning Outcomes in K-12 and Higher Education: A Meta-analysis[15]

- *Study Overview:* A comprehensive review of virtual reality-based instruction research was conducted with studies in order to analyze the moderation effects of design features in virtual environments. Studies were based on games (n=13), simulations (n=29), and virtual worlds (n=27), with key inclusion data being that the studies came from K-12 or higher education settings, used experimental or quasi-experimental research designs, and used a learning outcome measure to evaluate the effects of the virtual reality-based instruction.
- *Key Findings*:
    - Games show higher learning gains than simulations and virtual worlds.
    - For simulation studies, elaborate explanation-type feedback is more suitable for declarative tasks whereas knowledge of correct response is more appropriate for procedural tasks.
    - Students' performance is enhanced when they conduct the game play individually versus in a group. In addition, an inverse relationship was found between number of treatment sessions and learning gains with games.
    - With regards to the virtual world, it was found that if students were repeatedly measured, it deteriorated their learning outcome gains.

Implications for Development of Virtual Reality Experiences

Virtual reality technology and capabilities have advanced quickly in recent years. Implications for the development of the content and user experience have changed as the technology improves. While research is still needed to reflect these changes, several companies have designed best practices in the development of VRE. The ability for learning to effectively take place depends on the ability for a VRE to create a realistic environment for the user. A variety of factors can affect this experience and it is important to consider the various factors listed in the attached appendices when creating a user experience.

- See Appendix A for *Best Practices from Oculus Rift*
- See Appendix B for *Best Practices from Unreal Engine*
- See Appendix C for *Best Practices for the Creation of Immersive and VR Experience*

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[15] Merchant, Z., Goetz, E., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. (2014) Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. Computers and Education. 70, 29-40. https://doi.org/10.1016/j.compedu.2013.07.033

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Virtual Reality Technology Lab. Texas State School of Social Work. Retrieved from http://www.socialwork.txstate.edu/centers-institutes/VRTL.html

Appendix A- Best practices from Oculus Rift[16]

The following information is directly from the Oculus website and is intended to provide developers with best practices in developing virtual reality content made for Oculus Rift headsets. Consideration should be made when not using Oculus Rift headsets but implications below can also be translated to other headsets and types of VREs.

Rendering

[16] Oculus. *Introduction to best practices.* Retrieved from https://developer.oculus.com/design/latest/concepts/bp_intro/

- Use the Oculus VR distortion shaders. Approximating your own distortion solution, even when it "looks about right," is often discomforting for users.
- Get the projection matrix exactly right and use the default Oculus head model. Any deviation from the optical flow that accompanies real world head movement creates oculomotor issues and bodily discomfort.
- Maintain VR immersion from start to finish. For example, don't affix an image in front of the user, such as a full-field splash screen that does not respond to head movements, as this can be disorienting.
- The images presented to each eye should differ only in terms of viewpoint; post-processing effects (e.g., light distortion, bloom) must be applied to both eyes consistently as well as rendered in z-depth correctly to create a properly fused image.
- Consider supersampling and/or anti-aliasing to remedy low apparent resolution, which will appear worst at the center of each eye's screen.

Minimizing Latency

- Your code should run at a frame rate equal to or greater than the Rift display refresh rate, v-synced and unbuffered. Lag and dropped frames produce judder which is discomforting in VR.
- Ideally, target 20ms or less motion-to-photon latency (measurable with the Rift's built-in latency tester). Organize your code to minimize the time from sensor fusion (reading the Rift sensors) to rendering.
- Game loop latency is not a single constant and varies over time. The software development kit (SDK) uses some tricks (e.g., predictive tracking, TimeWarp) to shield the user from the effects of latency, but do everything you can to minimize *variability* in latency across an experience.
- Use the SDK's predictive tracking, making sure you provide an accurate time parameter to the function call. The predictive tracking value varies based on application latency and must be tuned per application.

Optimization

- Decrease eye-render buffer resolution to save video memory and increase frame rate.
- Although dropping display resolution can seem like a good method for improving performance, the resulting benefit comes primarily from its effect on eye-render buffer resolution. Dropping the eye-render buffer resolution while maintaining display resolution can improve performance with less of an effect on visual quality than doing both.

Head-tracking and Viewpoint

- Avoid visuals that upset the user's sense of stability in their environment. Rotating or moving the horizon line or other large components of the user's environment in conflict with the user's real-world self-motion (or lack thereof) can be discomforting.

- The display should respond to the user's movements at all times, without exception. Even in menus, when the game is paused, or during cutscenes, users should be able to look around.
- Use the SDK's position tracking and head model to ensure the virtual cameras rotate and move in a manner consistent with head and body movements; discrepancies are discomforting.

Positional Tracking

- The rendered image must correspond directly with the user's physical movements; do not manipulate the gain of the virtual camera's movements. A single global scale on the entire head model is fine (e.g. to convert feet to meters, or to shrink or grow the player), but do not scale head motion independent of interpupillary distance (IPD).
- With positional tracking, users can now move their viewpoint to look places you might have not expected them to, such as under objects, over ledges, and around corners. Consider your approach to culling and backface rendering, and so on.
- Under certain circumstances, users might be able to use positional tracking to clip through the virtual environment (e.g., put their head through a wall or inside objects). Our observation is that users tend to avoid putting their heads through objects once they realize it is possible, unless they realize an opportunity to exploit game design by doing so. Regardless, developers should plan for how to handle the cameras clipping through geometry. One approach to the problem is to trigger a message telling them they have left the camera's tracking volume (though they technically may still be in the camera frustum).
- Provide the user with warnings as they approach (but well before they reach) the edges of the position camera's tracking volume as well as feedback for how they can reposition themselves to avoid losing tracking.
- We recommend you do not leave the virtual environment displayed on the Rift screen if the user leaves the camera's tracking volume, where positional tracking is disabled. It is far less discomforting to have the scene fade to black or otherwise attenuate the image (such as dropping brightness and/or contrast) before tracking is lost. Be sure to provide the user with feedback that indicates what has happened and how to fix it.
- Augmenting or disabling position tracking is discomforting. Avoid doing so whenever possible, and darken the screen or at least retain orientation tracking using the SDK head model when position tracking is lost.

Accelerations

- Acceleration creates a mismatch among your visual, vestibular, and proprioceptive senses. Minimize the duration and frequency of such conflicts. Make accelerations as short (preferably instantaneous) and infrequent as you can.

- Remember that "acceleration" does not just mean speeding up while going forward; it refers to *any change in the motion of the user*, whether in direction or speed. Slowing down or stopping, turning while moving or standing still, and stepping or getting pushed sideways are all forms of acceleration.
- Have accelerations initiated and controlled by the user whenever possible. Shaking, jerking, or bobbing the camera will be uncomfortable for the player.

Movement Speed

- Viewing the environment from a stationary position is most comfortable in VR; however, when movement through the environment is required, users are most comfortable moving through virtual environments at a constant velocity. Real-world speeds will be comfortable for longer. For reference, humans walk at an average rate of 1.4 m/s.

- Teleporting between two points instead of walking between them is worth experimenting with in some cases, but can also be disorienting. If using teleportation, provide adequate visual cues so users can maintain their bearings, and preserve their original orientation if possible.
- Movement in one direction while looking in another direction can be disorienting. Minimize the necessity for the user to look away from the direction of travel, particularly when moving faster than a walking pace.
- Avoid vertical linear oscillations, which are most discomforting at 0.2 Hz, and off-vertical-axis rotations, which are most discomforting at 0.3 Hz.

Cameras

- Zooming in or out with the camera can induce or exacerbate simulator sickness, particularly if doing so causes head and camera movements to fall out of 1-to-1 correspondence with each other. We advise against using "zoom" effects until further research and development finds a comfortable and user-friendly implementation.

- For third-person content, be aware that the guidelines for accelerations and movements still apply to the camera regardless of what the avatar is doing. Furthermore, users must always have the freedom to look all around the environment, which can add new requirements to the design of your content.
- Avoid using Euler angles whenever possible; quaternions are preferable. Try looking straight up and straight down to test your camera. It should always be stable and consistent with your head orientation.
- Do not use "head bobbing" camera effects. They create a series of small but uncomfortable accelerations.

Managing and Testing Simulator Sickness

- Test your content with a variety of unbiased users to ensure it is comfortable to a broader audience. As a developer, you are the worst test subject. Repeated exposure to and familiarity with the Rift and your content makes you less susceptible to simulator sickness or content distaste than a new user.

- People's responses and tolerance to sickness vary, and visually induced motion sickness occurs more readily in virtual reality headsets than with computer or TV screens. Your audience will not "muscle through" an overly intense experience, nor should they be expected to do so.
- Consider implementing mechanisms that allow users to adjust the intensity of the visual experience. This will be content-specific, but adjustments might include movement speed, the size of accelerations, or the breadth of the displayed field of view (FOV). Any such settings should default to the lowest-intensity experience.
- For all user-adjustable settings related to simulator sickness management, users may want to change them on-the-fly (for example, as they become accustomed to VR or become fatigued). Whenever possible, allow users to change these settings in-game without restarting.
- An independent visual background that matches the player's real-world inertial reference frame (such as a skybox that does not move in response to controller input but can be scanned with head movements) can reduce visual conflict with the vestibular system and increase comfort (see Tracking).
- High spatial frequency imagery (e.g., stripes, fine textures) can enhance the perception of motion in the virtual environment, leading to discomfort. Use—or offer the option of—flatter textures in the environment (such as solid-colored rather than patterned surfaces) to provide a more comfortable experience to sensitive users.

Degree of Stereoscopic Depth ("3D-ness")

- For individualized realism and a correctly scaled world, use the middle-to-eye separation vectors supplied by the SDK from the user's profile.

- Be aware that depth perception from stereopsis is sensitive up close, but quickly diminishes with distance. Two mountains miles apart in the distance will provide the same sense of depth as two pens inches apart on your desk.
- Although increasing the distance between the virtual cameras can enhance the sense of depth from stereopsis, beware of unintended side effects. First, this will force users to converge their eyes more than usual, which could lead to eye strain if you do not move objects farther away from the cameras accordingly. Second, it can give rise to perceptual anomalies and discomfort if you fail to scale head motion equally with eye separation.

User Interface

- A User Interface (UI) should be a 3D part of the virtual world and sit approximately 2-3 meters away from the viewer—even if it's simply drawn onto a floating flat polygon, cylinder or sphere that floats in front of the user.

- Don't require the user to swivel their eyes in their sockets to see the UI. Ideally, your UI should fit inside the middle 1/3rd of the user's viewing area. Otherwise, they should be able to examine the UI with head movements.
- Use caution for UI elements that move or scale with head movements (e.g., a long menu that scrolls or moves as you move your head to read it). Ensure they respond accurately to the user's movements and are easily readable without creating distracting motion or discomfort.
- Strive to integrate your interface elements as intuitive and immersive parts of the 3D world. For example, ammo count might be visible on the user's weapon rather than in a floating head-up display (HUD).
- Draw any crosshair, reticle, or cursor at the same depth as the object it is targeting; otherwise, it can appear as a doubled image when it is not at the plane of depth on which the eyes are converged.

Controlling the Avatar

- User input devices can't be seen while wearing the Rift. Allow the use of familiar controllers as the default input method. If a keyboard is absolutely required, keep in mind that users will have to rely on tactile feedback (or trying keys) to find controls.

- Consider using head movement itself as a direct control or as a way of introducing context sensitivity into your control scheme.

Sound

- When designing audio, keep in mind that the output source follows the user's head movements when they wear headphones, but not when they use speakers. Allow users to choose their output device in game settings, and make sure in-game sounds appear to emanate from the correct locations by accounting for head position relative to the output device.

- Presenting non-player character (NPC) speech over a central audio channel or left and right channels equally is a common practice, but can break immersion in VR. Spatializing audio, even roughly, can enhance the user's experience.
- Keep positional tracking in mind with audio design. For example, sounds should get louder as the user leans towards their source, even if the avatar is otherwise stationary.

Content

- For recommendations related to distance, one meter in the real world corresponds roughly to one unit of distance in Unity.

- The optics of the Rift make it most comfortable to view objects that fall within a range of 0.75 to 3.5 meters from the user's eyes. Although your full environment may occupy any range of depths, objects at which users will look for extended periods of time (such as menus and avatars) should fall in that range.
- Converging the eyes on objects closer than the comfortable distance range above can cause the lenses of the eyes to misfocus, making clearly rendered objects appear blurry as well as lead to eyestrain.
- Bright images, particularly in the periphery, can create noticeable display flicker for sensitive users; if possible, use darker colors to prevent discomfort.
- A virtual avatar representing the user's body in VR can have pros and cons. On the one hand, it can increase immersion and help ground the user in the VR experience, when contrasted to representing the player as a disembodied entity. On the other hand, discrepancies between what the user's real-world and virtual bodies are doing can lead to unusual sensations (for example, looking down and seeing a walking avatar body while the user is sitting still in a chair). Consider these factors in designing your content.
- Consider the size and texture of your artwork as you would with any system where visual resolution and texture aliasing is an issue (e.g. avoid very thin objects).
- Unexpected vertical accelerations, like those that accompany traveling over uneven or undulating terrain, can create discomfort. Consider flattening these surfaces or steadying the user's viewpoint when traversing such terrain.
- Be aware that your user has an unprecedented level of immersion, and frightening or shocking content can have a profound effect on users (particularly sensitive ones) in a way past media could not. Make sure players receive warning of such content in advance so they can decide whether or not they wish to experience it.
- Don't rely entirely on the stereoscopic 3D effect to provide depth to your content. Lighting, texture, parallax (the way objects appear to move in relation to each other when the user moves), and other visual features are equally (if not more) important to conveying depth and space to the user. These depth cues should be consistent with the direction and magnitude of the stereoscopic effect.
- Design environments and interactions to minimize the need for strafing, back-stepping, or spinning, which can be uncomfortable in VR.
- People will typically move their heads/bodies if they have to shift their gaze and hold it on a point farther than 15-20° of visual angle away from where they are currently looking. Avoid forcing the user to make such large shifts to prevent muscle fatigue and discomfort.

- Don’t forget that the user is likely to look in any direction at any time; make sure they will not see anything that breaks their sense of immersion (such as technical cheats in rendering the environment).

Avatar Appearance

- When creating an experience, you might choose to have the player experience it as a ghost (no physical presence) or in a body that is very different from his or her own. For example, you might have a player interact with your experience as a historical figure, a fictional character, a cartoon, a dragon, a giant, an orc, an amoeba, or any other of a multitude of possibilities. Any such avatars should not create issues for users as long as you adhere to best practices guidelines for comfort and provide users with intuitive controls.

- When the avatar is meant to represent the players themselves inside the virtual environment, it can detract from immersion if the player looks down and sees a body or hands that are very different than his or her own. For example, a woman’s sense of immersion might be broken if she looks down and sees a man’s hands or body. Allowing players to customize their hands and bodies can dramatically improve immersion. If this adds too much cost or complexity to your project, you can still take measures to minimize contradictions between VR and reality. For example, avoid overtly masculine or feminine bodily features in visible parts of the avatar. Gloves and unisex clothing that fit in the theme of your content can also serve to maintain ambiguity in aspects of the avatar’s identity, such as gender, body type, and skin color.

Health and Safety

- Carefully read and implement the warnings that accompany the Rift (see www.oculus.com/warnings) to ensure the health and safety for you, anyone testing your content, and your users.

Image Safety and Photosensitive Seizures

- Certain types of images are believed to be capable of triggering photosensitive seizures in a small portion of the population.[1] The International Standards Organization is in the process of developing a standard for image content to reduce the risk of photosensitive seizures. You are responsible for staying abreast of the standards and literature on photosensitive seizures and image safety and designing your content to conform to the standards and recommended best practices on these subjects.
- [1] International Standard ISO/DIS 9241-391.2, Ergonomics of Human System Interaction – Part 391: Requirements, analysis and compliance test methods for the reduction of photosensitive seizures (approved and published pending periodical review).

Appendix B- Best Practices by Unreal Engine[17]

Unreal Engine VR Development

The following information is directly from the Unreal Engine website and is intended to provide developers with best practices in developing virtual reality content made for Unreal Engine. Consideration should be made when not using Unreal Engine but implications below may also be translated to developing VR content in general.

VR World Scale

Ensuring the correct scale of your world is one of the most important ways to help deliver the best user experience possible on VR platforms. Having the wrong scale can lead to all kinds of sensory issues for users, and could even result in Simulation Sickness. Objects are most easily viewed in VR when they are in a range of 0.75 to 3.5 meters from the player's camera. Inside of Unreal Engine 4 (UE4), 1 unreal unit (UU) is equal to 1 centimeter (CM). This means that objects inside of Unreal are best viewed when they are 75 UU to 350 UU away from the player's camera (when using VR).

Distance	Distance in Unreal Units (UU)
1 Centimeter	1 Unreal Unit
1 Meter	100 Unreal Units
1 Kilometer	100,000 Unreal Units

You can adjust the scale of your world using the World to Meters variable that is located under World Settings. Increasing or decreasing this number will make the user feel bigger or smaller in relation to the world around them. Assuming your content was built with 1 UU = 1 CM, setting World To Meters to 10 will make the world appear to be very big, while setting World To Meters to 1000 will make the world appear to be very small.

VR and Simulation Sickness

Simulation Sickness is a form of motion sickness that occurs when using HMD devices in a VR world. Simulation Sickness can greatly affect a user's VR experience and in some cases, ruin the VR experience altogether. To help reduce the likelihood of your user having a bad VR experience, follow the best practices listed below closely. If you do not do this, your users could end up having a very unpleasant VR experience.

- You must maintain frame rate, and ideally, a little bit of a buffer to make sure you're always over the HMD's native frame rate. Low frame rates are another trigger for

[17] *Virtual Reality Best Practices.* Unreal Engine. Retrieved from https://docs.unrealengine.com/latest/INT/Platforms/VR/ContentSetup/

Simulation Sickness, so make sure to optimize your project as much as possible. The following table shows the various HMD's UE4 supports, and the target frame rates your VR project needs to run at on those devices.

• HMD Device	• Target Frame Rate
• DK1	• 60 FPS
• DK2	• 75 FPS
• Rift Retail	• 90 FPS
• Vive	• 90 FPS
• Gear VR	• 60 FPS
• PSVR	• Variable up to 120 FPS

- Developers make the worst test subjects, because they are often used to using VR devices. Check your game as much as you can, with as many different people as you can, to make sure that you are not causing Simulation Sickness.
- Avoid cinematic cameras, or anything that takes control of camera movements away from the player, as this tends to be the biggest culprit of your user having a bad VR experience.
- Do not override the field of view (FOV) manually, and do not expose this to the end user for editing purposes. The value needs to match the physical geometry of the headset and lenses, which should be automatically set through the device's SDK and internal configuration. If there is a mismatch, the world will appear to warp when you turn your head, leading to discomfort or nausea.
- Do not have "Walking Bob" for a camera effect (like in most first person games). Causing the camera to move up and down to mimic the movement of the human body will give the player Simulation Sickness, ruining their VR experience.
- Do not "shake" the camera when trying to relay an event to the player. If a grenade goes off next to a player, a camera shake may make sense in non-VR games, but in VR games, it can trigger Simulation Sickness very quickly.
- When you are designing worlds and levels for your VR game, make sure to use dimmer lights and colors than you normally would. Strong and vibrant lighting in VR games can cause Simulation Sickness to occur more quickly. Avoid this by using cooler shades and dimmer lights than you normally would.
- Avoid stairs and use lifts instead. When the player is moving quickly, especially up and down stairs, it can be very disorienting.

- Players should all start out going full speed and not gradually accelerate to full speed. Also, movement speed should always be at a constant rate of acceleration.
- Do not use Depth of Field or Motion Blur post processes, because they can greatly affect what the user is seeing and, more importantly, they can give the user Simulation Sickness.
- Please note that this list is not an exhaustive compilation of root causes for Simulation Sickness; however, it should give you a good idea of what might be causing your players to fall ill while playing your VR game.

VR Character Settings

- The setup for a character using a VR headset is slightly different than for a standard character. Things like character height, width, speed, and camera location all need to be slightly modified to accommodate a VR character.
- When building objects for a VR world, it is important that you make the scale of your digital object the same as their real world counterpart. Making things bigger or smaller than they are in the real world, can ruin the immersion that you are trying to achieve.

Character Height and Width

- Character height and width should mimic real life measurements as much as possible. Using sizes that are too big or two small, can ruin the immersion that you are trying to achieve.

Property	UE4 Default	Recommended VR
Height:	192 cm	176 cm
Width:	84 cm	68 cm

Movement Speed

- VR movement speed is a difficult property to recommend a setting for, because the movement speed that you choose will mainly be determined by the type of experience that you are trying to achieve. For example, in the Elemental VR demo, the movement speed was cut to about 1/4 normal speed.

Property	UE4 Default	Recommended VR
Movement Speed:	60 m/s	24 m/s

Camera Location

- The VR camera needs to be positioned slightly lower than the base eye height to compensate for being at the character's eye level.

Property	UE4 Default	Recommended VR
Base Eye Height:	180 cm	160 cm

VR Content Considerations

When creating VR content, remember that users can look at that content from multiple angles. Here are few things that you might have done in the past, but need to avoid in VR:

- Scale - The best thing to do about the scale of the objects in your VR world, is to mimic reality as closely as you can. Making objects bigger or smaller than their real world counterparts could lead to confusion or Simulation Sickness.
- Missing polygon faces - In standard games, it is often acceptable (and preferred) to remove polygon faces from objects that cannot be seen by the player. However, in VR games, players have much more freedom to look around, and this practice can sometimes lead to players being able to see things that they're not supposed to see.
- Which type of lighting to use - You should always use static lighting and Lightmaps when making a VR project; this is the cheapest option to render. If you need to use dynamic lighting, make sure to limit the amount of dynamic lights to as few as possible, and make sure that they never touch one another. If you have an outdoor scene, set your directional light to dynamic instead of stationary, and then turn on Cascaded Shadow Maps (CSM); adjusting the settings to be as simple as possible while still giving you shadows.
- Near field effects, or effects that happen very close to the camera, work well in VR, but only when the effects are made up of static mesh particles.
- Fake everything you can - Finding clever ways to recreate expensive rendering options, like dynamic shadows or lighting, can be a huge win for hitting your performance goals in VR. In Showdown, having the characters cast dynamic shadows proved to be too expensive per-frame, which meant that dynamic shadows had to be cut from the project. However, this made the characters look like they were floating while moving. To fix this, fake blob shadows were introduced that could dynamically adjust their position and intensity based on how close the character was to an object in the world. This helped give the illusion that a character was casting shadows when they came close to the ground (or other objects).

Known VR Issues

Due to the manner in which HMD's work, some art techniques that are staples of video game development, no longer have the impact that they once did. Below, you will find a list of features that might not work as expected in VR, with possible workarounds to address this.

- Screen Space Reflections (SSR): While SSR will still work in VR the reflections that they produce could have issues matching up to what it is reflecting in the world. Instead of using SSR use Reflection Probes as they are much cheaper and do suffer less from reflection alignment issues.

Appendix C- Best Practices for the Creation of Immersive and VR Experiences[18]

In order to ensure the proper balance of curation, exploration, user immersion, and engagement, the next generation of immersive experience designers must develop and follow best practices for the creation of VR and AR experiences:

1. Map the User's Emotional Journey – The difference between non-immersive, digital experiences and immersive ones lies in the latter's potential to stimulate the user's emotions. As a result of these emotional immersive experiences, users have a higher degree of focus and engagement with the content. To create a compelling emotional journey for the user, designers need to map out and identify the types of experiences that will effectively produce the user's desired emotional state at appropriate moments in the experience.

2. Map the User's Physical Journey – Immersive, virtual reality experiences rely heavily on the design of the imagined environment, or, in the case of augmented reality, the overlay and projection of content and information on top of the user's actual, physical environment. In either case, the UX Designer must create an environmental map to represent the physical space that must be navigated. Doing so, enables exploratory and curated experiences to occur naturally, as the user moves through the experience.

3. Create Physical Laws and Experience Principles – We are able to comprehend and function effectively in our world because we are familiar with its natural laws, physics, and patterns. Even if a User Experience (UX) Designer wanted to create an entirely new world, he or she must first create guiding experience principles that, once learned, enable users to quickly become familiar and comfortable with their surroundings. That way, users focus more on having experiences and less on figuring out how to have one.

4. Use Audio in Addition to Video – One reason the Internet bears little resemblance to reality is because it is a predominantly silent universe. UX Designers have decided that audio may distract users when they are trying to complete tasks. With the exception of streaming videos and games, the Internet is largely a collection of silent tools for people to learn, communicate, and interact with brands. When creating VR experiences, however, designers are tasked with creating realistic or fantastical environments. Most environments, real or imagined, come alive with their own sounds. Audio adds dimension to physical spaces, increases engagement, and enhances the intended emotional tone. It is an essential component to telling a great story and creating a convincing world.

5. Allow Users to Interact via Directional, Extended Stare – User interaction and controls with mobile VR platforms are currently very limited. Google cardboard viewers (and their

[18] Lupo, J. (2016). Best Practices for the Creation of Immersive and VR Experiences. EPAM. Retrieved from https://www.epam.com/ideas/blog/best-practices-for-the-creation-of-immersive-and-vr-experiences

clones) enable simple interactions via a single button and Samsung VR has a button and a touchpad. There are some gamepads that claim to work as controls for mobile VR platforms on iOS and Android, but these are often difficult for consumers to pair via Bluetooth. Ensure great mobile VR experiences by giving users the option to stare for an extended period of time in a certain direction, placing a reticle over a menu item or user interface element, activating the selection.

6. Allow Users to Move Independently without Pointing Them in a Specific Direction – Mobile VR experiences are actually quite dangerous because users are untethered and free to wander about their real environment without being able to see and avoid real obstacles. To avoid lawsuits, UX Designers have developed some clever ways for users to wander about virtually. One workaround is to encourage users to look in a specific direction, and walk in place to move forward. Another workaround is to have users look in a specific direction, and tap or hold the hard button on the viewer to move forward (although this feels awkward and is a less natural behavior).

7. For Realistic VR, Use 3D and 360-Degree Video in Addition to Still Photography – VR experiences can feel quite artificial and game-like when designers use 3D models instead of photorealistic assets. While these choices may be appropriate for video games, they may not be the best choices for real-world experiences. When creating a realistic experience or for educational purposes, try to create environments using high-definition, 3D, and/or 360-degree video.