THE ROLE OF MEDIA NATURALNESS ON DYADIC COLLABORATION EFFECTIVENESS IN MIXED REALITY AND VIRTUAL REALITY

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

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May 2019

ABSTRACT

With the development of technology, the workplace is adopting new mediums to engage in collaborative work with others. The quality of this collaboration varies by the technology medium being utilized (Daft & Lengel, 1986; Kock, 2005); The goal of this research is to study the difference in collaboration effectiveness for people in mixed (MR) and virtual reality (VR) environments. Participants working in teams of two were given a collaborative idea generation task in MR or VR, at which point their collaboration effectiveness was measured through behavior, conversation, and reported experience. The results of this study showed no significant differences in dyad collaboration between conditions. Implications and directions for future research on this topic are further discussed.

BIOGRAPHICAL SKETCH

Cameron McKee is Masters Student at Cornell University, studying Human-Environment Relations, with a concentration in Environmental Psychology within the department of Design & Environmental Analysis in the College of Human Ecology, with a minor in Information Science. Previously, she earned her Bachelor of Arts degree from Illinois Wesleyan University, majoring in Psychology and Environmental Studies, with a concentration in Policy, and minoring in Human Services Management. She completed this thesis in accordance with the graduation requirements set forth by the Cornell Graduate School and the department of Design & Environmental Analysis in pursuit of a Master of Science degree.

ACKNOWLEDGMENTS

I would like to thank my friends and family for their love and continued support in my work. I would like to extend a special thank you to my parents Michael & Joanne McKee, and Alexander Contreras, in which this would not have been possible without. Their unconditional encouragement and words of inspiration motivated my efforts and continued endeavor for success. Specifically related to the development of this thesis, I would like to thank Teresa Bevacqua and Marty Schatz who aided in data coding and modeling environments, Nicole Contreras for editing efforts, and Jasmine Daniels and Jeffery Neo in counsel during data collection piloting.

Thank you to Dr. Ying Hua for her advising efforts and her work as the chair of my committee. Her assistance in research development, content editing, and general guidance have not only influenced my realization of this thesis, but also in the Masters program at Cornell University.

Thank you to Dr. Andrea Stevenson Won for her guidance and continued advising of my research. The recommendations, resources, and time Dr. Won invested in my work made it feasible and successful. This research would not have existed without her support.

In relation to resources used in this research I would like to thank Mark Zifchock in the development of my Mixed and Virtual Reality Environments. I would also like to thank Katy Miller and the entire Virtual Embodiment Lab at Cornell for technical help, recruiting, and resources. Finally, I extend a thank you to the Department of Design and Environmental Analysis at Cornell University for partially funding my research and providing the opportunity for me to pursue my academic interests.

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CHAPTER 1

INTRODUCTION

The roles of the office-based workforce have changed. Ushered by the technological revolution, the demand of workers has shifted from “left-brain” mechanical and routine tasks to “right-brain” creative and collaborative work. In the past, jobs in computing, manufacturing, and retail were operated by humans rather than machines. For example, from 1935-1970, the National Aeronautics and Space Administration (NASA) used human computers who performed mathematical equations and calculations by hand to translate manometer readings into data and graphs to be used by engineers. Since then, NASA has evolved to use machine computers with ever-increasing computing capabilities to achieve a plethora of space travel ventures (NASA, 2018). Because technology has taken on the burden of repetitive and routine work once in high demand in the workforce, employees are now being given more opportunities to stretch their brain and create innovative solutions to society’s problems (Ahmed, 2017). Because of this, a higher demand for collaboration in the workplace is being capitalized on as creative minds join together to do work (Neubert et al., 2015). Organizations that have increased the amount of teamwork done by their staff have seen increases in productivity, creativity, and individual fulfillment on the employee-level, as well as an increase in achieved company goals on the organization-level (Townsend, DeMarie, & Hendrickson, 1998). People are working together more in the workplace, and the benefits of this teamwork are far-reaching.

In addition to the shift from individual to group work and technical to creative work, there is also a change in the kinds of people with which work is being conducted. With collaborative work growing in popularity, people are trying to communicate more with potentially cohesive global workforces, rather than segmented local populations (Okoro & Washington, 2012). This growth invites an increase in cross-disciplinary, global communication for the sake of more diverse collaborative possibilities. To engage in this collaboration, people are using technology as a tool to reach across the earth and develop new enriching ideas. Technology-mediated collaboration encourages creativity and has shown to increase team performance and decision-making (Townsend et al., 1998). A tech company, Meta, is taking advantage of this transformation by utilizing technology to encourage more creative, collaborative work. Through the use of their augmented reality glasses, Meta anticipates next generation workplaces will communicate and collaborate with increased ease and fun compared to current computer-based office desk workstations (Horwitz, 2018). As this technology-guided social change in the workplace progresses, we are forced to ask: are the technologies being developed and utilized best for the task at hand?

Guided by this social change in the workplace, my research aims to understand what features of technology best suit the new kind of work humans will be doing in the office. Referencing two prominent theories about this subject, the media richness model and the psychobiological (media naturalness) model, I plan to identify a direction in which future workplace technology should be developed to best support computer-mediated communication for employee work.

Theoretical Basis

The Media Richness Model. The Media Richness model, developed by Daft & Lengel (1986), stipulates that the more characteristics/features a technology medium has, the more effective user communication will be. More specifically, a technology or medium is rich if it helps quickly and effectively communicates unclear information being transferred from one party to another. When this model was first proposed, authors ranked technologies from low to high levels of richness based on the criteria of features: numeric documents, impersonal written documents, personal documents (letters or memos), telephone calls, then face-to-face conversations (Daft & Lengel, 1986). Features that contribute to a medium's richness include the capacity for immediate feedback, the number of cues and channels utilized, the possibility for personalization, and the variety of languages (Daft & Wiginton, 1979). For example, face-to-face conversations were rated to be the richest medium of communication because one party can quickly clarify information with another party if confusion occurs, and both parties can use their body, face, and tone to support their worded message. Numeric documents were considered the least rich in this model because the medium communicates quantifiable information but lacks the opportunity to communicate any natural language (Lengel & Daft, 1984). Looking at the use of technology in the workplace through this model, technology mediums that provide users with an abundance of features are favorable because this richness will lead to better collaboration among coworkers.

Research on this theory has been widely variable. Measuring users perception of technology, studies have found strength in this theory. For example, studying how

65 managers across 11 organizations communicated via face-to-face interactions, over the telephone, by email, and via written media, Trevino and colleagues (1987) found that face-to-face communication was the most favorable, followed next by telephone and email. However, measuring objective performance has shown to be a different story. Valacich and colleagues (1994) measured the differences in teams working on tasks face-to-face, via video call, via a computer-mediated teleconferencing system, and over the phone and found that participants expressed a different communication medium hierarchy when rating preferences for technology versus perception of performance versus objective performance. Kraut and colleagues (2009) conducted research on the difference in media richness in collaborative scientific writing and discovered that when scientists collaborated using richer medium (i.e. voice annotation in manuscript editing rather than written), they produced better results (i.e., annotations were judged to be more useful). Kinney & Watson (1992) studied differences in dyadic communication in face-to-face, telephone, and computer mediated text completing high and low equivocal tasks and found no significant results to support the Media Richness Theory. Dennis and Kinney (1998) studied media richness on team decision making by exposing them to immediate and delayed feedback video conferencing, and immediate and delayed feedback computer mediated text communication technology, and found that subjects perceived differences in media richness but did not perform differently based on it. Generally, the field no longer recognizes this as a relevant theory, but for the sake of this research it is being used to frame the issue. In the instance of this research, the media richness

model poses the possibility that collaboration will be more successful in technology-mediated communication when the technology has more features available to the user.

The Psychobiological Model. In comparison, the Psychobiological Model states that the more natural a technology medium is, the better communication will be (Kock, 2005). More specifically, drawing from Darwin's evolutionary theory, the human brain has not evolved to optimally understand computer-mediated-communication because of the lack of availability for communication nuances, such as body language, that humans have developed over time, so technologies that present opportunities to communicate more naturally (i.e., face-to-face) will result in better user communication (Kock, 2005). Naturalness is defined through a series of factors that indicate a proximity to face-to-face interaction. These features include technology's degree of co-location (individuals are proximally close to each other, experiencing the same context), degree of synchronicity (individuals can readily share and receive communicative stimuli), ability to observe and express body language (individuals can freely move their body to express thoughts or emotions, and can observe the same in their partner), ability to observe facial expressions (individuals can freely move their face to express thoughts or emotions, and can observe the same in their partner), and ability to convey and listen to speech (individuals can speak freely and hear their partners speech without obstruction) (Kock 2004; Kock, 2005). For example, in this model, video chatting would be considered more natural than a phone call because each party can observe the others' face and body, in addition each party's ability to converse with and listen to each other. Looking at the use of technology in the workplace through this model, technology mediums that provide users with a more natural experience are favorable because face-to-face communication leads to better collaboration among coworkers.

The research exists on this theory is minimal but applies across a variety of fields. Kock, Verville, & Garza (2007) explored the changes in student performance and perception of media naturalness comparing traditional face-to-face learning versus online learning and found students at the middle of the semester felt their class to be more ambiguous and attained significantly lower grades, but then adjusted with no significant difference at the end of the semester. Studying how people engage in communication differently based on media naturalness, researchers found that, in accordance with the media naturalness theory, dyads speaking via face-to-face interaction or audio chat participated significantly more than those communicating via text chat because of user autonomy provided by the technology (Blau & Barak, 2012). Studying 462 new product development teams in industry, researchers found that teams communicating via technology expressed more difficulty working and were less effective in working than teams working face-to-face (Kock et al., 2006). Generally, this theory is still new and requires more research to fully understand its strength. In the instance of this research, the psychobiological model poses the possibility that collaboration will be more successful in technology-mediated communication when the tech allows for an experience that is most similar to face-to-face collaboration.

At the core of these models, there is the basic dichotomy between quality collaboration being elicited via the number of features, or how rich technology is, versus the level of naturalness, or how close the technology is to face-to-face communication.

Theory in Practice

When both the media richness model and the psychobiological model were first developed, technology was not as advanced as it is now. At the time these models were created, face-to-face communication was thought to elicit the highest quality communication. However, this thought poses some problems in today's technological environment. First, when comparing technologies on levels of richness or naturalness in the past, comparisons have not been appropriate because of the differences in the two forms of communication. For example, a video conference may elicit better collaboration than a phone call, but this may be because individuals have more features available to them in a video conference (e.g., screen sharing) or because it is closer to face-to-face communication. Comparing voicemail to email, researchers found that preference varied based on different facets of the theory due to the different abilities of each technology (El-Shinnawy & Markus, 1992). In a time with more primitive technology, face-to-face communication has been viewed as the highest form of communication because of its richness (Daft & Lengel, 1986). But if richness is held more close to constant, does the naturalness of a technology play a role in the effectiveness of collaboration? Now, with advanced tech like mixed and virtual reality, we have a more appropriate chance to understand the effects of varying levels of naturalness because the richness of the two environments is similar. Additionally, never before has technology given individuals the ability to participate in communication behaviors that are not available in reality (i.e., viewing large 3-D models uninhibited by gravity and accessible from multiple angles). Neither the media richness theory nor the media naturalness theory was developed with this advanced technology in mind. By giving users these hyper-realistic abilities, researchers are able to truly stretch both models beyond face-to-face communication as the peak form of collaboration, in order to understand what factors are really important for team interaction.

The dichotomy between these theories can be explored through the comparison of mixed and virtual reality. Both of these technologies provide users with the ability to experience information beyond their real-world environment. Using these advanced technologies to study the difference in team collaboration, the aforementioned theoretical models can be adequately tested within today's technological landscape.

Mixed reality is a technology that sits between augmented and virtual reality and augments the real world by anchoring virtual renderings within it (Forbes, 2018). Mixed reality can exist in many forms, but for the purpose of this research I will be using a head mounted display system (HMD) that adds computer-generated imagery on top of real-world objects (Baird & Barfield, 1999). Little research has been done studying mixed reality and collaboration. Müller, Rädle, & Reiterer (2016) studied how dyads interacted in a collaborative mixed reality environment (portrayed through hand-held tablet devices) and found team members preferred virtual objects as spatial cues in the environment rather than physical objects, which was expressed both via gesturing behavior and reported user experience. Using mixed reality in this study, participants will be able to see their typical surrounding environment, with task-relevant information displayed over their normal physical environment via the HMD.

Virtual reality is a computer-generated environment in which individuals immerse themselves, via head-mounted eye goggles and other technology, that allows them to act within this three-dimensional simulation (Steuer, 1992). Research on communication in virtual environments has shown how teams collaborate differently in this setting. Research studying communication in virtual environments (portrayed via Head Mounted Display) has shown that dyads perform best when each individual is represented via an animated avatar, and that increased movement is linked with increased task performance (Dodds, Mohler, & Bülthoff, 2010). Smith & Neff (2018) found that dyads working in VR environments with avatar behaved and experienced social presence at similar levels compared to those interacting face-to-face but significantly different for those working in VR without avatar representation. For the purpose of this study, participants will be wearing an HMD that immerses them in a virtual environment to engage in a collaboration task.

By comparing collaboration in a mixed reality and virtual reality environment, participants are exposed to a similar level of richness when communicating through technology, but their experience of naturalness is different.

This is important because, as the responsibilities of technology are exponentially growing in the workplace, we need to understand in what direction technology should be developing. How much can we rely on technology before it hinders our productivity? What kinds of technology are going to best support our future work? The answers to these questions may lie in understanding the differences in collaboration quality for teams interacting in technology-mediated environments of different naturalness.

Collaboration

Defining the guidelines of collaboration quality is increasingly difficult as research on it continues to be done. At its core, collaboration is defined as "an interpersonal process through which members… contribute to a common product or goal" (Bronstein, 2003). Common research practices on measuring this variable include analyzing collaboration content and behaviors.

Measuring collaboration by analyzing content is a straightforward way of understanding how teams worked together to achieve their goal. For example, through a series of design competition evaluations, Shah, Smith, & Vargas-Hernandes (2002) determined collaboration effectiveness in idea and product generation by measuring deliverables based on novelty, variety, quality, and quantity. Researchers in a lab studied how teams working via a computer-mediated communication technology versus face-to-face communication collaborated during divergent and convergent thinking tasks, and found that by measuring the total number of recommendations as well as percentage of irrelevant recommendations, computer-mediated teams collaborated better on divergent tasks and face-to-face teams collaborated better on convergent tasks (Kerr & Murthy, 2004). Girotra, Terwiesch, & Urlich (2010) studied the intricacies of collaboration by asking teams to collaborate on a task together or brainstorm independently and then collaborate, and found that, based on the principles of quality, quantity, variety, and group consensus, teams whose participants were given time to individually brainstorm before collaborating performed better than teams who solely engaged in idea generation through collaboration. On a larger scale, researchers analyzed the number of co-authored publications to understand the success of collaboration between university-industry partnerships (Lundberg et al., 2006). Whatever the scale or task, one evident way in which researchers typically measure collaboration is through analysis of collaboration outcomes.

Another way in which collaboration success can be measured is through behaviors in which collaborators engage. Studying employment negotiation, Curhan and Pentland (2007) found that teams with individuals who spoke more and mirrored their partners in speech within the first 5 minutes of collaboration were more likely to settle on a favorable outcome. In industry, researchers found that people who are geographically close to each other are more likely to collaborate well with innovative results, so long as the people are not constantly within close proximity to each other and have space to brainstorm individually (Kraut et al., 2002; Letaifa & Rabeau, 2013). Hoegl & Proserpio (2004) found that software development teams that could easily call a spontaneous face-to-face meeting and whose members were in the direct vicinity of each other and easily reachable by foot were more productive and produced higher quality work compared to teams who collaborated with greater geographic distance. Pentland (2010) reported that mirroring in speech and body movement increases empathy and trust among individuals, leading groups of peers who mirrored each other more in collaboration to be more productive. Researchers studying group performance found that teams whose individuals speak roughly an equal amount are more successful in a wide variety of intelligence tasks than those whose speaking ratios were disproportionate (Woolley et al., 2010). Similarly, a study at Google found that their most successful teams are those who collaborate and engage in an equal distribution of turn taking (Duhhig, 2016). Studies have shown that a variety of behavior can predict collaboration success in teams.

Overall, both behavior analysis as well as content analysis has been used to measure collaboration success. Because individuals' collaboration conversation or end product is not isolated without behavior, it is recommended that both of these factors are measured in collaboration research.

Present Research

So, in this technology-rich workplace, how valuable is face-to-face communication? When media richness is held constant, does media naturalness influence communication? If environmental factors are comparable, will the quality of collaboration for teams change if individuals can see each other more naturally while interacting? Based on prior literature and current trends in the field, it is predicted that, with most factors held constant, teams will engage in better quality collaboration if they can see each other more naturally while communicating. I hypothesize that technology with features that allow for more natural communication will significantly positively impact the quality of collaboration within computer-mediated communication. Therefore, I believe that teams using mixed reality to communicate will engage in better collaboration than those using virtual reality. This successful collaboration for teams in mixed realty will be evident by greater success in collaboration task, as well as more speech and body movement mirroring equal speaking time, even speaking balance, and closer proximity between team members compared to teams collaborating in virtual reality.

CHAPTER 2

METHODS

Study Design

This study is a between-groups, simple, post-test only design. The type of environment exposure (Mixed Reality or Virtual Reality) served as the independent variable and the quality of collaboration served as the dependent variable

Participants

Fifty-two students from Cornell University were recruited for this study. All participants were enrolled in a graduate or undergraduate program at the time of the study and ranged in age from 18-27 years (73% Female, 23% Male, and 3% chose not to self-identify). Demographic specifics on the sample are available in Appendix J. This sample was derived via recruitment through Cornell's Psychology and Communication/Information Science SONA Systems, and participants were compensated for their participation with two SONA credits for their hour-long session. People who were prone to motion sickness or other balance and dizziness conditions, were pregnant, had experienced a recent concussion, had seizure disorders, maintained a history of fainting or seizures, had a visual impairment that wasn't corrected via glasses or contacts, had hearing disabilities that were not corrected via hearing aids or other assistive devices, or any condition that made them prone to dizziness or disorientation were excluded from participation in the study.

Setting

Trials for this study were conducted in a designated Communications Department laboratory at Cornell University, which was specialized for virtual reality research (Figure 1). This lab was a 380cm X 450cm room with a ceiling height of 321cm. The room also housed two lighthouses in opposing corners of the room for adequate virtual room setup. During each trial, a researcher was always in the room for safety reasons, to prevent participants from running into each other, tripping, or other possible accidents. Participants' conversations were recorded via Zoom H2n Handy Recorder microphone and transcribed via Otter.ai for later analysis. This microphone was located on a desk in the middle of the room along the back wall, and captured all vocalizations by participants during the collaboration task.

Figure 1. A panoramic image of the lab in which research trials were run.

A desk with a computer, head-mounted display (HMD), two hand controllers, two control-button covers, and a sociometric badge were available to each student. The HMD was an HTC Vive Pro, which provided a mixed or virtual reality environment that participants were immersed in. The mixed reality environment allowed participants to view the lab as in reality (as it appears in Figure 1), with a task-related image projected into the space. Participants had the opportunity to move around the lab and interact with the other participant as usual. The virtual reality environment was rendered to look similar to the lab. In this environment, the same task-related image was projected in the same spot within the space. Participants were represented by avatars in the virtual environment and could move around the environment and interact with other participants via avatar. For images of teams working in the space, see Appendix K.

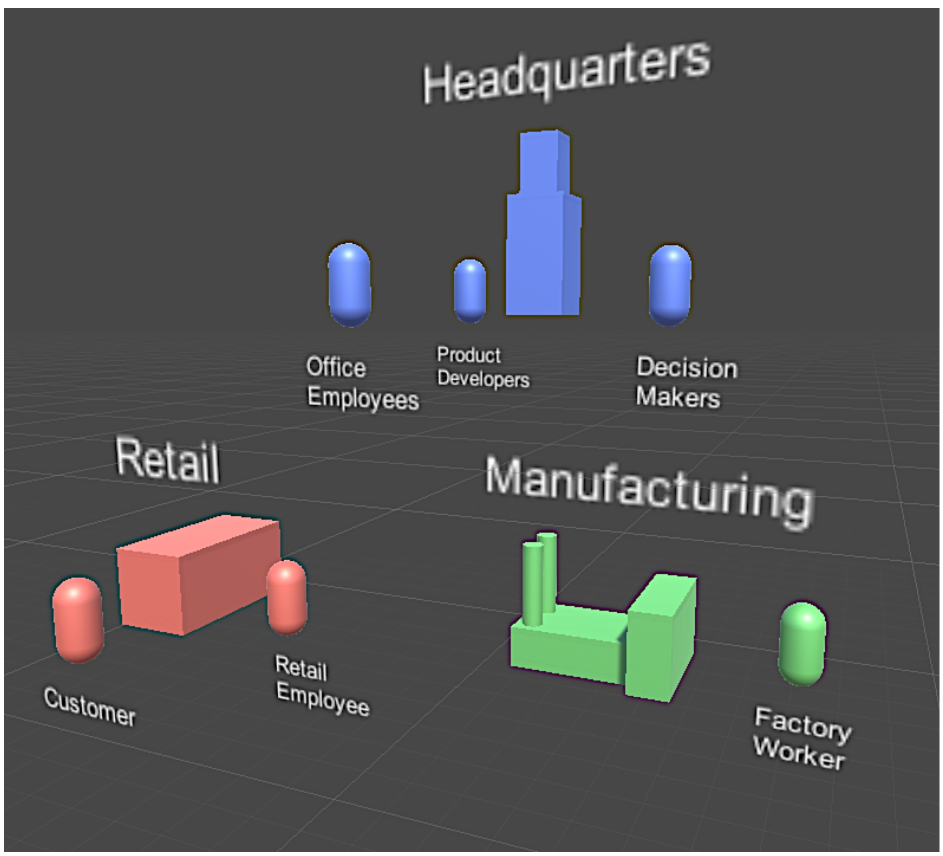

Figure 2. The task related virtual image participants could view through their HMD. This is a network/general organization of the business participants were creating ideas for while working together in their environment.

The task related image (Figure 2) projected into the environment is a 3-D network symbolizing the general organization of a retail business. This was created as a combination of various academically based supply-chain models that best fit the task participants engaged in (IIBM, 2015; Abecassis-Moedas, 2006; Harland, 1996). In this model, three sectors of the organization were presented with corresponding stakeholders. Highest on the model was the Headquarters sector of the business, with Decision Makers, Office Employees, and Product Developers shown as associated stakeholders. Below Headquarters was the Manufacturing sector, with Factory Workers shown as the associated stakeholder. On the same level as Manufacturing, Retail was the last sector with Retail Employees and Customers shown as associated stakeholders. This image was displayed in the room near the door and started approximately 92cm from the floor.

Tools

To engage in the virtual or mixed reality environment, participants wore an HTC Vive Pro headset with two hand-held controllers (See Appendix A). Controllers were encased in a sleeve that prevented participants from pressing buttons while completing the task. With these tools, participants were able to view and walk around the environment while pointing or gesturing as desired.

While completing the collaboration task, participants also wore sociometric badges to measure their collaborative behavior (See Appendix B). These badges were worn around a participant's neck, on their chest immediately below their chin. These badges are small data-collecting devices gathering information on a participant's mimicry behaviors, speaking time, and proximity to each other during the collaboration task. Verbal mimicry behavior was measured via mirroring speech volume and frequency through the microphone located on the front of the badge. Speaking time was measured as total time each participant spent speaking per second, gathered from the front facing microphone. Proximity was measures by the total amount of time participants spent within close proximity (less than one meter) of each other by the Bluetooth module feature of the badge (Olguin & Pentland, 2008). All of this data was collected simultaneously via the small sociometric badges worn around participants' necks while completing the collaboration task.

Measures

Quality of collaboration was measured by the uniqueness and number of ideas developed by a team during their task. This measure is an adaptation from the creativity coding procedure used by Won et al. (2014). After receiving transcriptions of the team task session, two independent judges rated the effectiveness of collaboration based on quantity (total number of generated ideas), and quality (determined by uniqueness and feasibility of ideas) (Won et al., 2014). In relation to quantity of ideas, one point was assigned to each idea generated by the team. An idea was given zero points if it was impossible or unfitting (e.g., "shut down the company"). In relation to quality of ideas, one point was given to each idea if it was unique and original. If the idea was repeated or reworded from the fifteen principles listed in the prompt (e.g. rephrasing "provide all employees with a reusable water bottle to save energy" to "give everyone metal water bottles"), it was given zero points. Two judges coded each collaboration session independently based on the aforementioned criteria. The average of the two scores determined by the judges were used to rate the effectiveness of collaboration. The quality and quantity of ideas for each team was considered to determine the overall quality of collaboration via conversation.

After collaborating, participants were asked to complete a post-task survey, which consisted of a variety of measures used primarily to understand participants experience during the session and to control for potential confounding variables. To control for participants' environmental knowledge, they were given an adapted Perceived Environmental Knowledge Scale (see Appendix C). This 5-item measure is rated on a 5-point Likert scale (1= completely disagree, 5= completely agree) adapted by Mostafa (2007) with a reported chromach alpha of 0.86. User experience in the environments was measured via the User Experience Questionnaire (UEQ) (See Appendix D). This is a 26-item measure rated in a 7-point Likert scale, asking participants to rate their experience between two opposing descriptive words (i.e., 1= Annoying, 7= Enjoyable) with sufficient reliability (Laugwitz, Held, & Schrepp, 2008). Social closeness (See Appendix E) between the participants during collaboration in the environments was measured via a modified Social Distance survey developed by Won et al. (2018). This 11-item measure rated on a 5-point Likert scale asks participants about the extent to which they felt socially adjacent to their partner (1= not at all, 5= very strongly), with a reported alpha of 0.93 (Won et al., 2018). A Social Presence measure (See Appendix F) asked participants their feelings about the presence of their partner during the collaboration session. This modified 4-item measure is rated on a 5-point Likert scale (1= not at all, 5= very strongly) with a reported alpha of 0.71 (Bailenson et al., 2005).

Procedure

Before beginning each trial, participants were randomly assigned to either mixed reality or virtual reality conditions based on an online tool Decode (https://www.dcode.fr/random-selection). This random condition assignment was designated by creating a set of all possible trials, requesting one element to be selected at a time, without replacement, and to repeat this selection process thirty times. These condition assignments were known ahead of time to the researcher but not participants.

Once conditions were assigned and individuals signed up to participate in the study via the SONA systems, each trial was broken down into three sections: Introduction, Task, and Survey. During the entire session, the researcher followed the same script for each trial to ensure each participant received the same information. A complete script is available in Appendix G.

When participants entered the lab, they were asked to store their belongings out of the way, read and sign an informed consent form. They were then introduced to what it meant to work in VR or MR and asked to read through a PowerPoint presentation about their specific task. This presentation (See Appendix H) informed participants that their job was to generate sustainability ideas to help improve a company in hopes to be hired by them in the future. They were then introduced to fifteen water conservation principles to help brainstorm ideas (Won et al., 2018). They were not required to memorize these principles, but were informed not to repeat the principles or example solutions during their idea generation session. After reading through this presentation, the researcher asked participants to reiterate what they thought their task was, to verify they understood what was being asked of them. The researcher also answered any questions participants had, and then moved on to help set them up in their environment.

As the first step of the set-up, the researcher asked participants to put on their sociometric badges around their neck, directly below their chin, then adjust them to be at chest height. The researcher then went to each desk and helped participants individually put on their headsets, pull up their environment, and orient them in the space. To orient students, the researcher made sure participants could see the virtual image and asked them to take a few steps to make sure they were comfortable moving in the space.

Once both participants were set in in their environment, the researcher turned on each participants' badges, reminded them of their task and allotted time, started recording the conversation, then told them to begin. For five minutes, participants worked together to generate as many sustainability ideas for the business (their potential future client) as possible. The researcher remained in the room the entire time participants were wearing their HMDs for safety reasons, to help avoid tripping or potential accidents.

After five minutes, participants were asked to stop their tasks and removed from their environment. Their badges were turned off, and brief surveys were pulled up on laptops for participants to complete individually. Participants were informed that their answers were anonymous, so they should complete the survey as honestly as possible. The researcher then left the room while students completed their surveys.

Before leaving, participants were asked if they felt any dizziness or motion sickness-like symptoms. If so, they were asked to stay until this subsided. Participants were thanked for their time, compensated with two SONA credits, and free to leave.

Data Analysis

Statistical analyses were performed using SPSS version 25 for Mac. Significance was set at $p>0.05$ for all statistical tests. Linear mixed model tests were used to compare the differences in collaborative behavior for individuals in teams in mixed reality versus virtual reality. At the team level, an independent samples t-test was used to understand the difference in the conditions for teams' conversation score and proximity measure. To understand interactions between variables and potential condition effects, a correlational matrix was created. Any significant correlations between variables of different types (behavior, conversation performance, and experience) were analyzed via MANOVA with environmental condition set as the independent variable to understand if MR/VR played a role in relationships between dependent variables. To control for variables explored via survey, linear mixed model tests were also used to identify any significant differences in populations for the two conditions.

CHAPTER 3

RESULTS

Mixed vs. Virtual Reality

Collaboration Behavior. Collaborative behavior was measured via speech volume mirroring, speech frequency mirroring, body mirroring, speaking time and team proximity during the five-minute collaboration session. In order to understand the difference in collaborative behavior a linear mixed model analysis was conducted to see if individuals in teams behaved significantly differently depending on their environmental condition for all mirroring behavior, and speaking time. In this analysis, the environmental condition variable was identified as fixed because it was the independent variable of this study, and the team identification variable was identified as random because its label is important in individual participant categorization but not data analysis. Five teams had to be dropped in the behavior data analysis due to technical difficulties with sociometric badge data collection.

Speech volume mirroring was measured via sociometric badges on the individual level, in which each team member received a score between 0 (no mirroring) and 1 (exact mirroring) for each second of the five-minute session. These scores were then averaged over the entire session, and each participant was given a singular mirroring score to rate their speech volume mirroring while collaborating. The same practice was used for speech frequency mirroring and body mirroring. Figure 1 below shows the distribution of mirroring behavior scores for individuals in mixed and virtual reality. Averaging all participant scores per condition together, participants in mixed reality mirrored each other's speech volume about the same (μ=0.2421, SD=0.0402) as those in virtual reality (μ=0.2366, SD=0.0256), mirrored each other's speech frequency less (μ=0.2173, SD=0.0307) than those in virtual reality (μ=0.2307, SD=0.0249), and mirrored each other's body movement about the same (μ=0.2248, SD=0.0148) as those in virtual reality (μ=0.229, SD=0.0193).

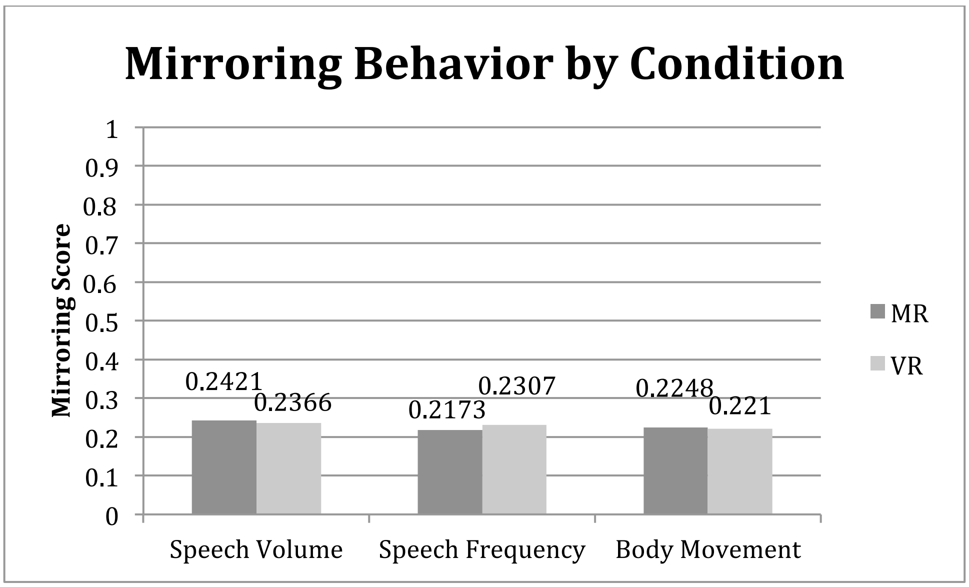

Figure 3. This graph shows the difference in mirroring behavior for participants that collaborated in MR and VR. Mirroring behavior was measured via mirroring in speech volume, mirroring in speech frequency, and mirroring in body movement.

There was no significant difference in volume mirroring depending on condition, $F(1,19)=0.163$, $p=0.691$. There was no significant difference in frequency mirroring depending on condition, $F(1,19)=1.308$, $p=0.267$. There was no significant difference in body mirroring depending on condition, $F(1,19)=0.360$, $p=0.556$. Therefore, participants did not vocally or physically mirror each other differently based on whether they interacted in mixed or virtual reality.

Speaking time was measured via sociometric badges on the individual level, in which each team member's speaking was recorded by the second in the five-minute conversation. These scores were summed per each one-minute section as well as for the entire session to determine any speaking patterns over time and between conditions. Figures 4 and 5 show the average amount of time participants spoke during the session broken down by minute. Due to the researcher needing to set participants up in the collaborative environment one at a time, Participant 1 was always the first one in the environment and Participant 2 was always the second. On average, teams working in mixed reality spoke about the same amount, with Participant 1 speaking 41.95 seconds in Minute 1 (SD= 11.3197), 42.91 seconds in Minute 2 (SD= 10.4344), 46.32 seconds in Minute 3 (SD=10.2073), 45.04 seconds in Minute 4 (SD=8.3559), and 46.23 seconds in Minute 5 (SD=9.6007), while Participant 2 spoke 38.95 seconds in Minute 1 (SD=12.6539), 39.57 seconds in Minute 2 (SD=9.1528), 42.14 seconds in Minute 3 (SD=6.8146), 39.01 seconds in Minute 4 (SD=7.9779), and 35.03 seconds in Minute 5 (SD=9.8155). In total, in mixed reality, Participant 1 spoke more (μ=222.45, SD=22.5571) than Participant 2 (μ=194.7, SD=29.3643). On average, teams working in virtual reality spoke about the same amount, with Participant 1 speaking 41.5909 seconds in Minute 1 (SD= 7.4394), 48.74 seconds in Minute 2 (SD=11.5779), 46.9909 seconds in Minute 3 (SD=8.0879), 47.4727 seconds in Minute 4 (SD=7.4396), and 45.8182 seconds in Minute 5 (SD=10.1393), while Participant 2 spoke 30.5 seconds in Minute 1 (SD=13.2014), 42.0273 seconds in Minute 2 (SD=13.6149), 39.9364 seconds in Minute 3 (SD=9.0131), 39.0455 seconds in Minute 4 (SD=10.9047), and 33.9181 seconds in Minute 5 (SD=10.5544). In total, in virtual reality, Participant 1 spoke more (μ=230.6091, SD=34.8295) than Participant 2 (μ=185.4272, SD=47.8831).

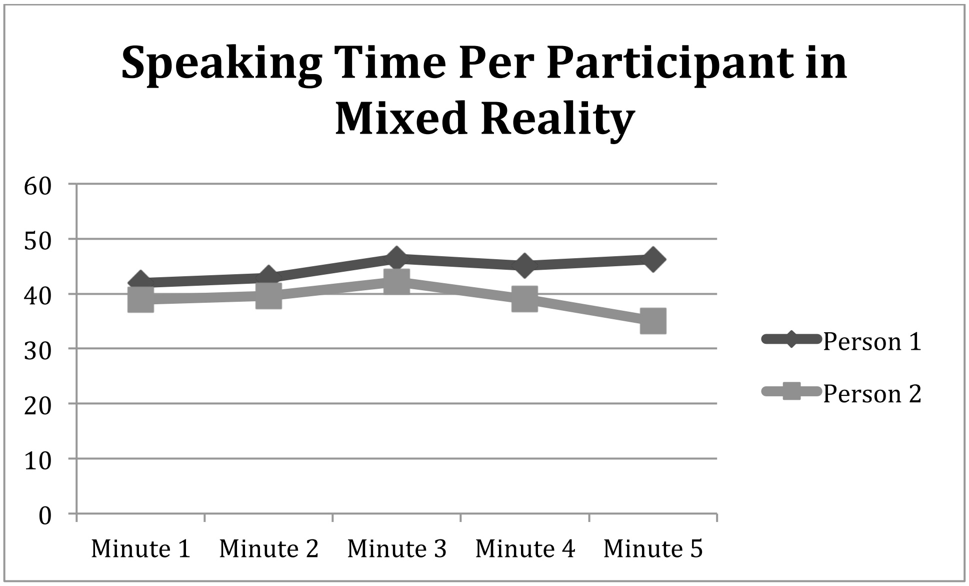

Figure 4. This graph shows the difference in speaking time in MR for person 1 and 2 over the five-minute collaboration session.

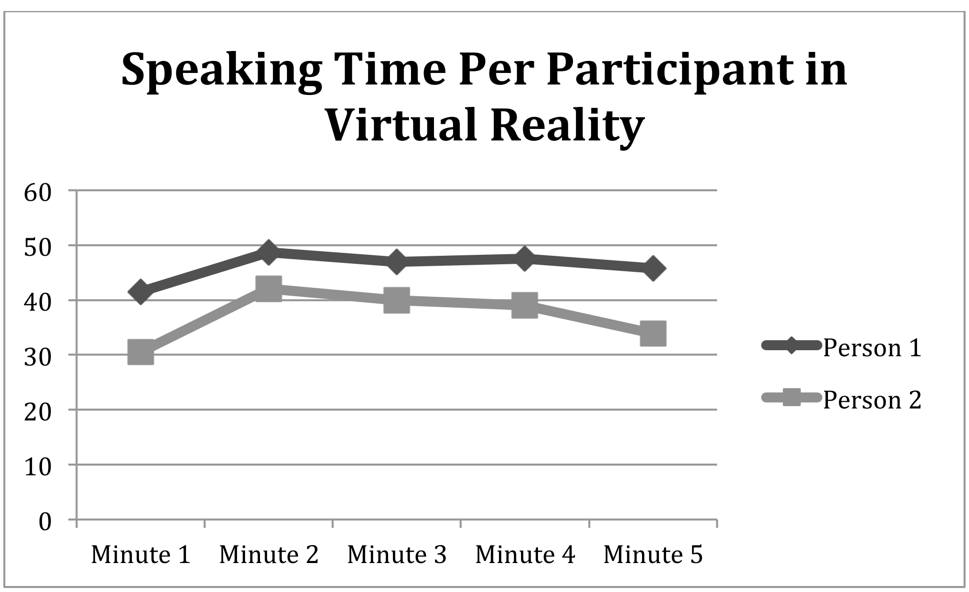

Figure 5. This graph shows the difference in speaking time in VR for person 1 and 2 over the five-minute collaboration session.

When analyzing speaking balance between participants for each condition, the absolute difference was calculated between speaking times for each participant during each minute segment and totaled. Then, an independent samples t-test was conducted to understand if there was a difference in speaking balance between participants in mixed versus virtual reality. The analysis revealed no significant difference in total speaking balance for participants in mixed reality (246.31 ± 102.505) versus virtual reality (229.3 ± 64.778), $t(19)=-1.431$, $p=0.169$. This analysis was then broken down by speaking balance per minute to understand if there was a significant difference in speaking balance per condition (see Table 2). Collectively, this indicates that even when broken down by minute, there was no difference in speaking balance between participants in mixed reality versus. virtual reality.

Table 2. Results of independent-samples t-test analysis: Difference in speaking time between participants during each minute of collaboration session

	Minute 1	**Minute 2**	**Minute 3**	**Minute 4**	**Minute 5**
t- test	0.469	-0.661	-0.467	-1.004	-0.074
p-value	0.644	0.517	0.646	0.325	0.942
MR (Mean ± SD)	(16.7 ± 12.778)	(12.9 ± 12.039)	(13.22 ± 7.887)	(12.13 ± 8.11)	(16.06 ± 11.278)
VR (Mean ± SD)	(14.282 ± 10.835)	(16.373 ± 12.024)	(15.018 ± 9.581)	(15.936 ± 9.161)	(16.318 ± 10.856)

To identify if there was a difference in overall speaking per condition, a linear mixed model analysis was conducted to understand whether participants in mixed reality teams spoke more than those in virtual reality teams. In relation to total speaking time, there was no significant difference for participants between the two conditions, $F(1,40)=0.002$, $p= 0.964$. To understand if speaking changed over time by condition, the effect of condition on speaking time was analyzed at each minute mark during the five-minute idea generation session (See Table 3). Collectively this indicates that, even when analyzed at the minute level, environmental condition did not significantly influence the amount of time participants spoke during idea generation.

Table 3. Results of Linear Mixed Method analysis: Speaking time by condition during each minute of collaboration session

	Minute 1	**Minute 2**	**Minute 3**	**Minute 4**	**Minute 5**
F-value	1.449	1.374	0.077	0.182	0.046
p-value	0.236	0.248	0.782	0.672	0.831

Proximity was measured via sociometric badges on a team level in which the time participants spent within one meter of each other during the five-minute collaboration session was measured by second. This time was totaled for each team and proximity time was compared by condition. Figure 6 shows the time teams in each condition spent on average within one meter of each other. On average, teams working in mixed reality appear to have spent less time near each other ($\mu=175.3$, $SD=105.076$) than teams working in virtual reality ($\mu=221.27$, $SD=70.392$).

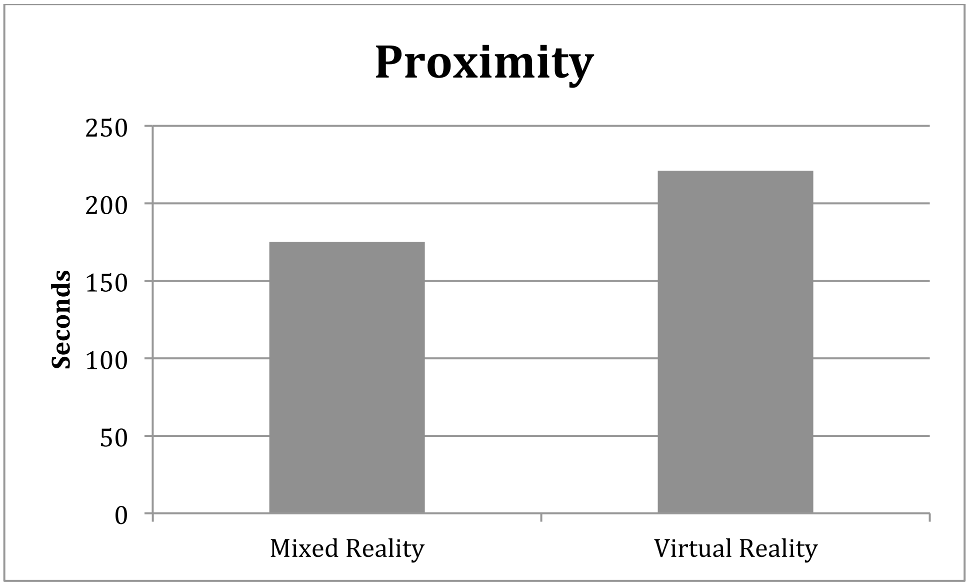

Figure 6. This graph shows the difference in proximity behavior between teams working in MR and VR. Proximity was quantified by the amount of time team members spent within one meter of each other.

An independent samples t-test was conducted to see if team members were close to each other for a significantly different amount of time based on their environmental condition. This analysis revealed that although it appeared as though mixed reality participants (175.3 ± 107.956) spent more in close proximity to each other than virtual reality participants (221.27 ± 72.131), there was no significant difference, $t(30)=-1.136$, $p=0.273$. This means that participants were not within one meter of each other for a significantly different amount of time based on if they collaborated in mixed or virtual reality.

Conversation Performance. Conversations were recorded via a microphone and transcribed via Otter.ai software. Each transcription was then scored by quantity and originality of ideas by judges. Figure 7 shows the average scores of teams working in mixed and virtual reality. On average, teams working in mixed reality scored lower on their conversations (μ=20.15, SD=6.104) than those working in virtual reality (μ=24.77, SD=8.42).

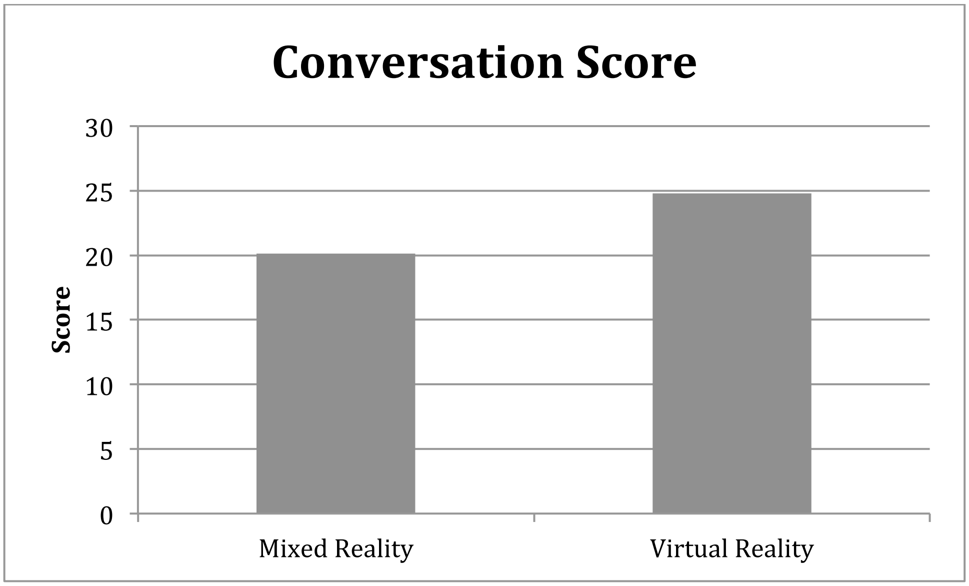

Figure 7. This graph shows the difference in conversation scores between teams working in MR and VR.

Because conversations were scored on a team level, an independent samples t-test was conducted to understand the difference in conversation success based on environmental condition. There was no significant difference in conversation score for teams working in mixed reality (20.14 ± 6.230) versus virtual reality (24.77 ± 8.594), $t(24)=-1.568$, $p= 0.13$. This means that participants did not perform significantly different in their idea generation task based on whether they collaborated in mixed or virtual reality.

Perceived Experience. All perceived experiences measures were collected via survey on the individual level, so a linear mixed model analysis was conducted to understand how participants perceived experiences differed based on their time in mixed or virtual reality. The Social Distance Questionnaire, User Experience Questionnaire, and Social Presence Questionnaire were all used to measure participant experience.

Perceived social distance was used to measure how socially close participants felt to their partner, and was measured at the individual level via post-task survey. Figure 8 shows the difference in overall scores based on condition. On average, participants scored about the same on their perception of social distance in mixed reality (μ=39.27, SD=7.159) and virtual reality (μ=39.81, SD=6.02).

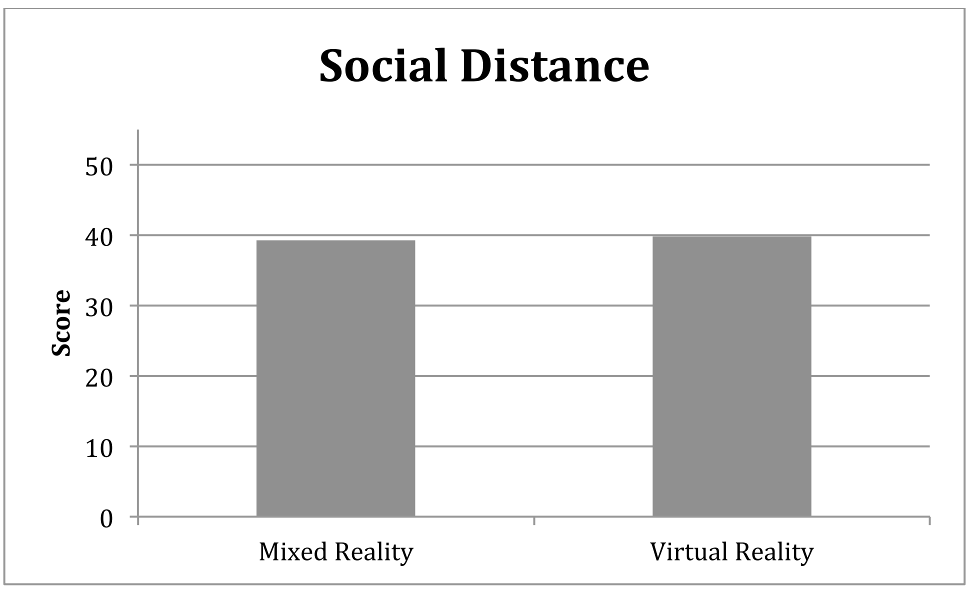

Figure 8. This graph shows the difference in perceived social distance for individuals working in MR and VR, as measured via the Social Distance Questionnaire.

Overall, there was no significant difference in participants' perceived social distance score based on their condition, $F(1,24)=0.059$, $p=0.81$. Additionally, broken down by individual item in the measure, there was no significant difference in participants' feelings of social closeness to their teammate except in the case of perception of their partner through the headset. When a participant was asked to what extent they felt that the partner they saw through their headset resembled their partner in reality, there was a significant difference in response for those in mixed reality versus those in virtual reality, $F(1,24)=30.405$, $p<0.001$. There is a significant positive correlation between this item and condition ($r=-0.615$, $p<0.001$). This indicates that participants in mixed reality felt that the partner they saw in their headset resembled their partner in reality significantly more than participants in virtual reality. However, generally participants in mixed and virtual reality experienced no significant difference in social distance.

The UEQ was collected on the individual level and used to measure how participants experienced their time using the technology based on a six user experience factors: perspicuity, attractiveness, dependability, efficiency, stimulation, and novelty. Figure 9 shows the reported difference in these factors based on condition. On average, participants working in mixed reality reported about the same level of perspicuity ($\mu=15.8462$, SD=2,7084) as those in virtual reality ($\mu=15.2692$, SD=2.3075), about the same level of attractiveness ($\mu=21$, SD=1.7205) as those working in virtual reality ($\mu=21.6538$, SD=2.2968), about the same level dependability ($\mu=14.4231$, SD=2.6401) as those working in virtual reality ($\mu=14.8462$, SD=2.428), about the same level of efficiency ($\mu=15.6154$, SD=2.6342) as those working in virtual reality ($\mu=15.4231$, SD=2.4847), a higher level of stimulation ($\mu=16.0385$, SD=2.3406) than those in virtual reality ($\mu=15.4615$, SD=1.9643), and about the same level of novelty ($\mu=15.8462$, SD=2.7084) than those working in virtual reality ($\mu=15.2692$, SD=2.3075).

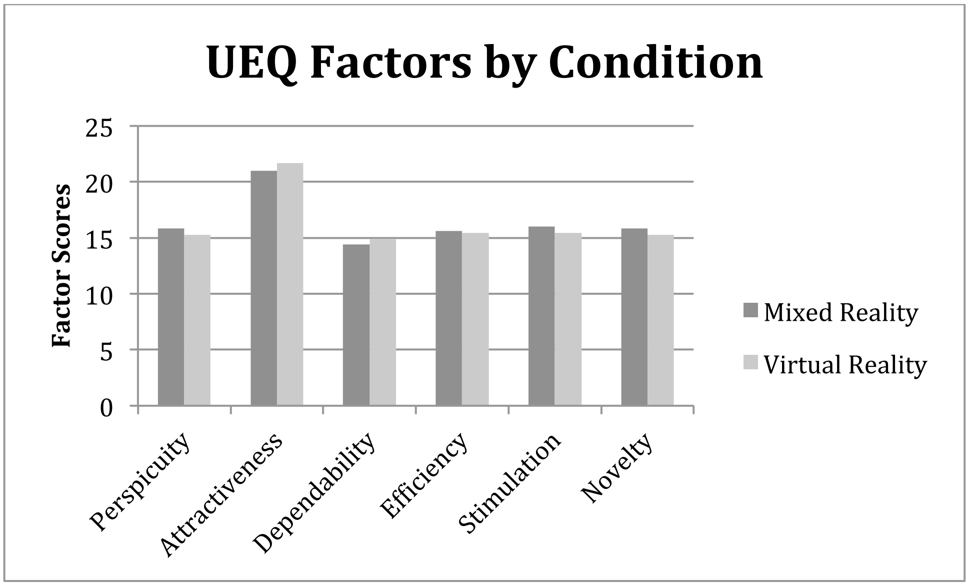

Figure 9. This graph shows the difference in perceived user experience for individuals working in MR and VR, as measured by the User Experience Questionnaire.

Participants' responses to items on the User Experience Questionnaire were totaled into six subscales: Attractiveness, Perspicuity, Dependability, Efficiency, Stimulation, and Novelty (Laugwitz et al., 2008). These subscales report how individuals described their experience based on UX factors (see table 4).

Table 4. Results of Linear Mixed Method analysis: UX Factor by condition

	Attractiveness	**Perspicuity**	**Dependability**	**Efficiency**	**Stimulation**	**Novelty**
F-value	1.242	0.558	0.362	0.074	0.888	0.558
p-value	0.276	0.462	0.55	0.787	0.335	0.462

However, addressing individual items in the questionnaire, participants did report significantly different experiences between mixed and virtual reality when given the dichotomy between boring-exciting, $F(1,50)=4.223$, $p=0.045$, and attractive-unattractive $F(1,24)=7.224$, $p=0.013$. A correlational analysis reveals that there is a significant slight negative correlation between the boring-exciting item and condition ($r=-0.216$, $p=0.045$), which indicates that participants found the mixed reality environment to be more exciting than the virtual reality environment. There is a significant slight positive correlation between the attractive-unattractive item and condition ($r=0.375$, $p=0.006$), which indicates that participants found virtual reality to be more attractive than mixed reality. The analysis also indicated a significant slight negative correlation between the impractical-practical dichotomy and condition ($r=-0.275$, $p=0.048$), which means that participants rated mixed reality more practical than virtual reality. However, there was no significant difference reported for the linear mixed model analysis in this relationship $F(1,24)=3.581$, $p=0.071$. Even though the relationship between this item and condition was strong enough to be recognized in a correlational analysis, the linear mixed model test did not find the report of different levels practicality by condition to be strictly due to the difference in condition. Likely, a confounding variable is responsible for the correlational relationship between the impractical-practical item and condition. So it cannot be concluded that participants reported a significant difference in practicality due to their experience in mixed or virtual reality, but rather this relationship is likely due to an alternative unmeasured variable or chance. Collectively, participants reported no difference in any factor of user experience based on their condition.

Perceived social presence was used to measure how individuals perceived their partner's presence while collaborating, and was measured at the individual level via post-task survey. Figure 10 shows the difference in overall social distance scores based on condition. On average, participants scored about the same in mixed reality (μ=16.96, SD=2.676) and virtual reality (μ=16.73, SD=3.157).

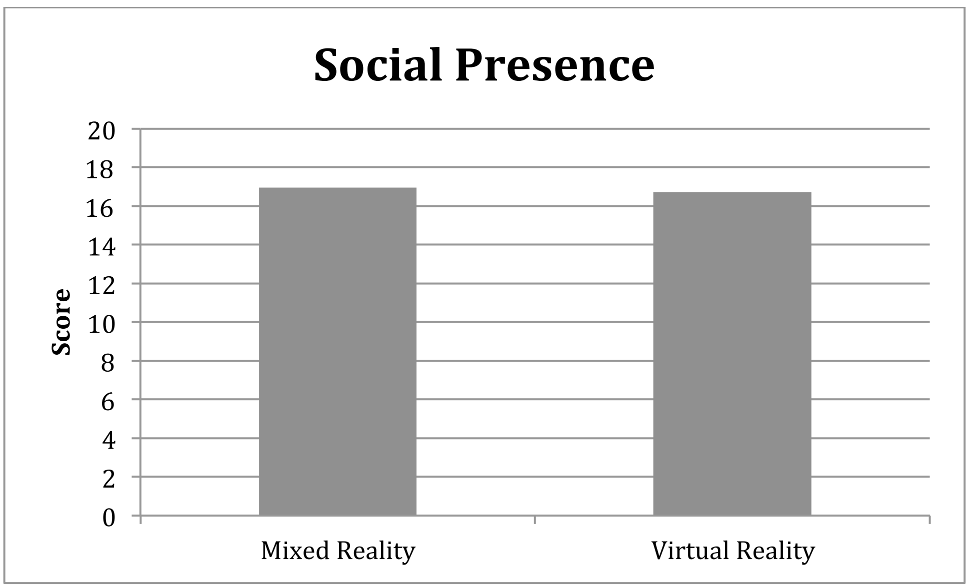

Figure 10. This graph shows the difference in perceived social presence for individuals working in MR and VR, as measured by the Social Presence Questionnaire.

Overall, there was no significant difference in reported social presence based on condition F(1.24)=0.074, p=0.788. There was also no significant difference for any individual item on the questionnaire. This indicates that participants' perception of their partner's presence during collaboration was not significantly different based on whether they interacted in mixed or virtual reality.

Variable Interaction

Moving from simple condition effects to more complex interactions, the relationships between dependent variables were analyzed addressing the effects of condition. To explore how variables may have influenced each other, a bivariate correlation was conducted on all dependent variables (See Table 1 in Appendix I). If correlations were significant, one-way MANOVAs were conducted on dependent variables of different types (Behavior vs. Conversation vs. Experience) to understand if the condition that participants interacted in played a role on the relationship between their behavior, conversation, and reported experience. This method of analysis was conducted because we are interested in the relationship of two dependent continuous variables and the potential mediation of one categorical independent variable.

Behavior vs. Conversation. There were no significant correlations between conversation score and any collaborative behavior. This indicates that participants' team idea generation did not change with their collaborative behavior.

Conversation vs. Experience. There were no significant correlations between conversation score and any reported experience. This indicates that participants' experience in mixed or virtual reality did not change with their team idea generation.

Behavior vs. Experience. There were many reported correlations between participants' collaborative behaviors and their experience in mixed a virtual reality. After identifying these correlations, a one-way MANOVA was conducted to understand if experiment condition had an influence on the relationship between the two variables.

There was a significant positive correlation between proximity and Social Distance score (*r*=0.376, p=0.019). A one-way MANOVA revealed that environmental condition did not significantly influence the relationship between these two variables, $F(2, 49)= 0.67$, $p=0.516$; Wilk's $\Lambda=0.973$, partial $\eta^2=0.027$. This indicates that regardless of environmental condition, the closer participants physically got to each other, the more socially close they felt to each other.

There was a significant positive correlation between frequency mirroring and UEQ perspicuity scores (*r*=-0.428, p=0.005), UEQ attractiveness scores (*r*=0.355, p=0.021), UEQ stimulation scores (*r*=0.307, p=0.048), and UEQ novelty scores (*r*=-0.428, p=0.005). A one-way MANOVA revealed that environmental condition did not significantly influence the relationship between frequency mirroring and UEQ perspicuity scores, $F(2, 39)=1.2$, $p=0.312$; Wilk's $\Lambda=0.942$, partial $\eta^2=2.399$. A one-way MANOVA between frequency mirroring and UEQ attractiveness scores revealed that environmental condition did not significantly impact the relationship between these two variables, $F(2,39)=1.192$, $p=0.314$; Wilk's $\Lambda=0.942$, partial $\eta^2=0.058$. A one-way MANOVA between frequency mirroring and UEQ stimulation scores revealed that environmental condition did not significantly impact the relationship between these two variables, $F(2,39)=2.566$, $p=0.09$; Wilk's $\Lambda=0.884$, partial $\eta^2=0.116$. A one-way MANOVA revealed that environmental condition did not significantly influence the relationship between frequency mirroring and UEQ Novelty scores, $F(2,39)=1.2$, $p=0.312$; Wilk's $\Lambda=0.942$, partial $\eta^2=0.058$. These results indicate that regardless of whether participants interacted in mixed reality or virtual reality, as participants mirrored each other's voice frequency during the collaboration session, they reported their user experience to be more perspicuous, more attractive, more stimulating, and less novel.

In relation to the amount of time participants spoke, there are significant correlations between speaking time at various minute marks and reported experience. There was a significant positive correlation between speaking time during minute three and UEQ attractiveness scores (r=0.330, p=0.033). A one-way MANOVA revealed that environmental condition did not significantly impact the relationship between speaking time during minute three of the session and UEQ attractive scores, $F(2,39)= 0.172$, $p=0.842$; Wilk's $\Lambda=0.991$, partial $\eta^2=0.009$. This means that the more time participants spoke during the third minute of the collaboration session, the higher they rated their UX experience in the headset as attractive, regardless of environmental condition. There was a significant positive correlation between speaking time during minute four of the session and UEQ stimulation score (r=0.399, p=0.009). A one-way MANOVA revealed that environmental condition did not significantly impact the relationship between these two variables, $F(2,39)=0.924$, $p=0.405$; Wilk's $\Lambda=0.955$, partial $\eta^2=0.045$. This means that the more time participants spoke during the fourth minute of the collaboration session, the higher they rated their UX experience as stimulating, regardless of whether they experienced mixed reality or virtual reality. There was a significant negative correlation between speaking time during minute five of the session and their perceived social presence (r=-0.432, p=0.004). A one-way MANOVA revealed that environmental condition does not significantly influence the relationship between these two variables, $F(2,39)=0.047$, $p=0.954$; Wilk's $\Lambda=0.998$, partial $\eta^2=0.002$. This indicates that, regardless of environmental condition, the more participants spoke during Minute 5 of the collaboration session, the less they felt like their partner was present during the session. Overall, these speaking time results indicate that as the amount of time a participant spoke during the end of the collaboration session changes, their reported experiences also change, and this relationship is not dependent on whether the participants were in mixed or virtual reality.

Control

In order to make sure that various factors did not confound the results, participants' scores on the Perceived Environmental Knowledge Scale (PEKS) and demographics were compared between conditions.

Perceived Environmental Knowledge. Perceived environmental knowledge was measured individually during the post-task survey to understand how familiar individuals were with sustainability. Figure 11 shows the difference in scores by condition. On average, participant scored about the same in mixed reality (μ=15.31, SD=3.438) and virtual reality (μ=15.58, SD=3.501).

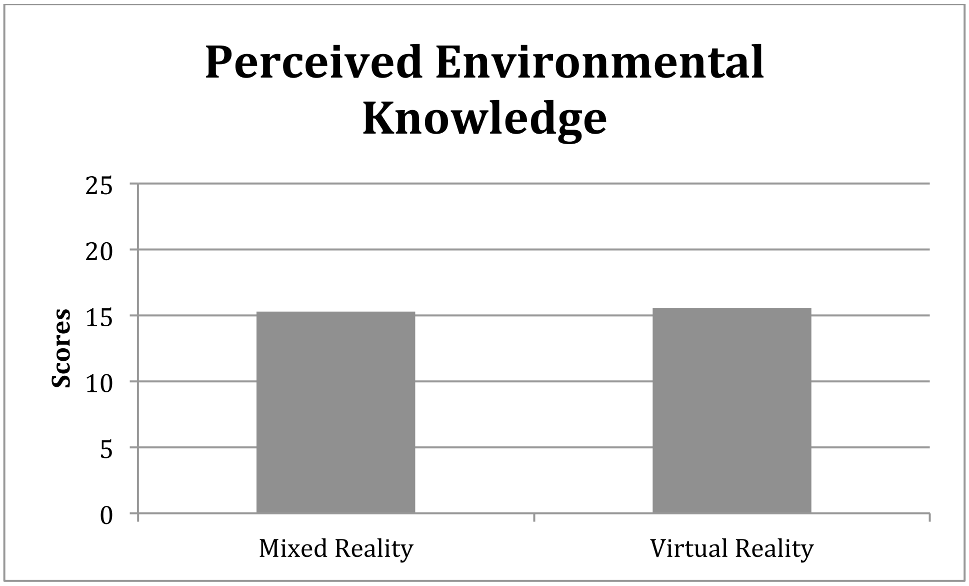

Figure 11. This graph shows the difference in perceived environmental knowledge for individuals working in MR and VR, as measured by the Perceived Environmental Knowledge Scale.

A linear mixed model analysis was conducted to understand if participants in different conditions scored differently on the PEKS. There was no significant difference in PEKS score based on condition, $F(1,24)=0.073$, $p=0.790$. This indicates that participants in the mixed reality condition did not know a significantly different amount about sustainability and the natural environment compared to participants in virtual reality.

Demographics. Demographic information was collected on the individual level during the post-task survey. A linear mixed model analysis was conducted to understand if various participant demographics were significantly different between mixed reality and virtual reality participants. See Appendix J for figures of demographic data. There was no significant difference in participant age based on condition, $F(1, 24.12)=0.081$, $p=0.778$. There was no significant difference in participant gender based on condition, $F(1, 50)=0.09$, $p=0.765$. There was a significant difference in participant nationality based on condition, $F(1, 24)=6.973$, $p=0.014$. There was no significant difference in the language participants spoke between conditions, $F(1,24)=1.681$, $p=0.207$.

Other Analysis

During the setting setup, Participant 1 was always in the collaboration environment longer than Participant 2, and was allowed free exploration of the space while the researcher set up Participant 2 in the environment. Because of this, a series of independent-samples t-tests were conducted to understand if there was a significant difference in behavior or experience based on this difference in environment exposure. All tests were insignificant other than measures of speaking time. Participant 1 spoke significantly more (226.723 ± 29.205) than Participant 2 (189.843), $t(40)=3.443$, $p=0.001$. Broken down by minute, there was a significant difference in speaking time between Participant 1 and Participant 2 during every minute segment except for Minute 2 (see Table 5). Altogether this indicates that participants who were in the collaborative environment first spoke significantly more than participants who were in the collaborative environment second.

Table 5. Results independent t-test analysis: Speaking time by participant during each minute of collaboration session

	Minute 1	**Minute 2**	**Minute 3**	**Minute 4**	**Minute 5**
t- test	2.004	1.460	2.183	2.738	3.822
p-value	0.048	0.152	0.035	0.009	0.000
Participant 1 (Mean ± SD)	(41.762 ± 9.239)	(45.962 ± 11.176)	(46.671 ± 8.928)	(46.314 ± 7.787)	(46.014± 9.64)
Participant 2 (Mean ± SD)	(34.524 ± 13.338)	(40.857 ± 11.487)	(40.986 ± 7.923)	(39.029 ± 9.386)	(34.448 ± 9.969)

CHAPTER 4

DISCUSSION

The results of this study allude to the relationship between collaborative success and immersive technologies. The following section discusses what these results mean in relation to the hypotheses of this research and suggests direction for future research.

Mixed vs. Virtual Reality

In this study, collaboration behavior, conversation, and reported experience were measured between teams interacting in mixed and virtual reality to understand how teams collaborated and experienced the environments differently based on varying levels of naturalness.

Collaborative Behavior. From the results, it is indicated that there was no overall significant difference in collaborative behavior between teams interacting in mixed or virtual reality. This indicates that teams working in mixed reality did not mirror each other in speech volume, frequency, body movements, speaking time, speaking balance, or physical proximity to each other whether they were working in mixed or virtual reality. This does not support the hypothesis that teams working in mixed reality would engage in different collaborative behaviors than those in virtual reality. The similarity in speech frequency, speech volume, and body movement mirroring per condition indicates that participants behaved the same in both conditions. This could be due to a true indifference in environmental conditions' effect on behavior, or it could be due to a lack of experience in a headset. An alternative explanation for the lack of behavior change is possibly that participants are not familiar with working in an immersive environment and therefore behave differently because of this inexperience. This could be remedied in the future by asking participants to rate their experience and comfort working with immersive technology as a control, or including a non-technology control condition in which participants complete the collaboration task without a headset.

The similarity in speaking time between conditions indicates that participants spoke about the same amount in mixed and virtual reality. One important factor to consider in this finding is the way in which this data was collected. Speech data was determined by the total time individuals spent speaking per second, as measured by the sociometric badges. These badges measured every instance of speaking, and were unable to differentiate whether the speaking was contributing to the conversation or not. For example, a participant that may have been speaking to him/herself was not engaging in collaboration but this was still measured as speaking time by the badges. Alternative or additional technology should be considered to control for this measurement error in the future.

The difference in proximity of two participants between conditions was considered insignificant, but maintained a relatively low p-value of 0.273. Although it was not statistically significant, teams in mixed reality spent less time in close proximity to each other than in virtual reality. Other research has indicated that when teams are engaged in computer-mediated collaboration, the closer people are while collaborating, the worse they collaborate (Valacich et al., 1994). Therefore, this result shows that people in mixed reality may have collaborated more effectively than those in virtual reality. However, he results on this measure were insignificant, which may be attributed to details of the headset, specifically the wire that connected the headset to the computer. Participants may have felt less inclined to move around during the session because the wire may have been hindering movement. One participant even claimed, "I feel like I'm on a leash". The setup of the headset also could have influenced how participants moved during collaboration, and future wireless technology might be able to provide a more clear difference between participant proximity behaviors in these two conditions.

Although there were no significant differences in collaborative behavior between conditions, there is still a possibility to identify differences with alternative methods. Mirroring behavior, speaking time, and proximity were not significantly different, but controlling for headset experience and using other tools to measure these variables may reveal a difference in conditions.

Conversation Performance. From the results, there was no significant difference in conversation score, but it appeared to be close to significant with a p-value of 0.13. On average, teams in virtual reality performed better than mixed reality in their conversation. On the basis of this measure, teams collaborated better in virtual reality than mixed reality. This result contradicts my hypothesis that mixed reality teams would collaborate better than virtual reality teams. Although this contradicts the media naturalness theory, which insists that technologies closer to reality will result in better collaboration, other research on creativity accounts for this difference (Hemlin, Allwood, & Martin, 2008; McCoy & Evans, 2002). Because the virtual reality condition is an environment different from what people normally experience, this stimulation may have encouraged creativity in participants, therefore prompting generation of a greater quality and quantity of scores. Even though the results found in this study were not significant, a larger sample size may reveal a noteworthy difference in conversation score.

Perceived Experience. From the results, it is indicated that there are no significant differences in perceived experience between those who experienced mixed reality or virtual reality. This means that teams working in mixed reality did not report a significantly different social distance score, user experience score, or social presence score compared to those in virtual reality.

The lack of difference in perceived social distance could be attributed to the nature of the environments. Although the visual environment participants were seeing were different by condition, participants could still see each other before and after the collaboration session, and could hear each other without the use of microphones or speakers in the headset. While these factors were the same in both conditions, it would be interesting to study whether participants seeing each other before collaborating plays a role in their perceived social distance. However, because these factors were the same in both condition and there was no control environment, it is appropriate to claim that their environmental condition did not play a role in the perception of social distance. One item in the measure that was significant was when participants were asked if they felt the partner they saw in their headset resembled their partner in real life. Participants that worked in mixed reality reported significantly higher scores than those working in virtual reality. This makes sense because those in mixed reality saw the normal room with a virtual image in it and their partner with a headset on. They also saw their partner put their headset on, so following Piaget's theory of object permanence (Piaget, 1954), it is logical that participants in this condition believed the person they saw through their headset was also what they looked like in real life. Similarly, because participants in virtual reality were represented by a virtually rendered avatar, it is logical for them to feel like their partner in the headset (appearing as a non-customizable avatar) did not resemble their partner in reality. Other than this finding, there was no difference in perceived social distance for participants working in mixed or virtual reality.

There was no significant difference in any of the UEQ factors for participants who experienced mixed or virtual reality. Participants' ratings of attractiveness were different with an insignificant p-value of 0.276, but this indicates that people working in virtual reality found their experience more attractive than those working in mixed reality. This finding matches the individual significant item attractive-unattractive, in which participants reported virtual reality to be significantly more attractive than virtual reality. This may be due to the less detailed rendering that made the virtual reality environment less cluttered, or it may be due to the fuzziness of the camera feed in mixed reality that caused people to rate its attractiveness lower. Repeating this research with a larger sample size may provide greater clarity in this distinction. Another significant correlation occurred with the boring-exciting item in this measure, in which participants reported mixed reality to be more exciting than virtual reality. This may be due to the novelty of the experience, and measuring participants' prior exposure to these kinds of technologies could provide a potential explanation for this result. An additional item that showed a significant correlation was the impractical-practical item in this measure. Interestingly, however, statistics did not indicate that the difference in reports between groups was due to environmental condition. Considering the high amount of environmental control during testing, participants should have only experienced a difference in immersive environment between conditions. Further research with a larger sample size could look into this difference to understand if there is a true reported difference in practicality between mixed and virtual reality, or if this observed difference is due to sample size of this study. Future research should consider repeating this study with a greater sample size to determine true differences in experiences between mixed and virtual reality.

There was no significant difference in social presence for participants who experienced mixed or virtual reality, indicating that participants did not perceive their partner's presence differently based on environmental condition. The lack of difference for this measure could be attributed to two possible factors. This could be due to the fact that this adapted social presence measure is only four items long and therefore lost power when shortened. To amend this in future research, the entire social presence questionnaire should be used to fully understand participants' perception of their partner. The lack of difference could also be attributed to the lack of a control. It is unclear if the difference could be due to environmental condition or technology novelty. It is possible that mixed and virtual reality are not different enough to warrant different perceptions of social presence.

Overall, there were no significant differences in reported experience for participants in mixed reality or virtual reality. This goes against the media naturalness theory that insists user hierarchy of mixed reality over virtual reality due to levels of naturalness (Kock, 2004). Larger sample sizes with a control condition could strengthen these results in the future and reveal a better picture of the difference between mixed reality and virtual reality in terms of participant experience.

Interactions

The only significant interactions between dependent variables occurred while comparing participants' behavior with their reported experience.

The significant relationship between social distance and physical proximity indicates that as participants got physically closer to each other, they also felt socially closer to each other. This relationship was expected because it has been widely observed in human behavior and perception (Boschma, 2005; Balland, Boschman, & Frenken, 2015).

The significant relationships between speech frequency mirroring and many UEQ factors show that as speech behavior changes, reported experience also changes. In this study, it was observed that as speech frequency mirroring increased, user experience perspicuity increased, attractiveness increased, stimulation increased, and novelty decreased. As described by Hari (2007), humans have a tendency to mirror each other in order to connect, which produces positive feelings when we do. It is likely that increased mirroring in speech frequency resulted in increased reported experiences because the mirroring behavior and feedback could have caused participants to feel connected and happy, therefore leading to a better session and rating the experience more favorably.

There were also relationships between speaking time and reported experience. Participants who spoke more during the middle of the collaboration session (Minute 3) perceived their experience to be more attractive than those who spoke less during Minute 3. Participants who spoke more during Minute 4 reported their experience to be more stimulating. These findings reveal a potential relationship between speaking time and UX factors. This makes sense because people who are speaking are potentially more involved in their task and engaged with their environment compared to someone not speaking and engaging in the task. Arguably, these participants could have rated their experience as more attractive and stimulating because they were acting more within it. Participants who spoke more during Minute 5 reported a lower social presence, meaning that those who spoke a lot during the end of the session felt less socially close to their partner while collaborating. It is possible that participants near the end of the session were speaking to fill the space, rather than to productively contribute to the task. Research states that humans often practice the behavior of speaking to fill an uncomfortable silence as an act of altruism to help their conversational partner feel less uncomfortable (Smith, 2006). Considering a number of participants near the end of the idea generation session exclaimed things such as “five minutes is a long time” or “I’m out of ideas”, it is possible that this “speaking to avoid awkward silence” behavior was occurring and therefore participants speaking during the last minute of the session were not doing so productively, but simply as an act of avoidance, therefore not connecting with their partner and feeling socially distant as a result.

A variety of behavior and experience variables were correlated with each other but further analysis indicated that none of these correlations were due to environmental condition. In other words, participant’s experiences changed with their behaviors, but their exposure to mixed or virtual reality did not impact these relationships. Some of the aforementioned research has identified these relationships and attributed them to general human behavior, and environmental condition in this study did not deviate the practices typically portrayed by humans.

Control

Results showed that there was no significant difference between participants' environmental knowledge or demographic information, other than nationality, between conditions. According to demographic analysis, the identified nationalities of participants in mixed reality was significantly different than those in virtual reality. Participants in virtual reality primarily identified as white, while nationality identification was more diverse for those working in mixed reality. This is a probable result of the overall demographics of the institution at which the research was conducted. A larger sample size in future research would likely resolve this difference. Other than this difference, the participants between conditions were similar and thus observed data is likely representative of a larger population.

Other Analysis

An interesting relationship viewed in the data is that of speaking time and environment exposure. Participants who were set up in the environment first spoke more than participants who entered the environment second. Because of the way research was conducted with one researcher and two participants, the researcher had to set up the participants in their environment one at a time. After Participant 1 was set up, the researcher suggested to Participant 1 that he or she explore the space as the researcher set up Participant 2. This gave Participant 1 more time in the environment to get accustomed to the environment, and gave the participant more time to freely explore the space without rules or guidance. Research suggests that novel experiences spark creativity (Gurman, 1989). This unintended effect may have occurred during the study as participants who had more time in their environment were more creative and felt more comfortable speaking during the idea generation session. Unfortunately, exposure to the environment was not randomized, so participants on one side of the room were always set up before participants on the other side. The lack of randomization muddles the strong observed relationship between exposure and speaking time. Further research is needed to control for confounding variables to understand if environment exposure leads to participants speaking more.

Theoretical Application

This research fails to support the media naturalness theory. Kock's prediction of communication in a super-rich virtual reality environment says that the medium would require too much cognitive effort, induce information overload, and result in poorer communication than face-to-face practices (Kock, 2004). However, the research here shows no significant difference in communication behavior and collaboration quality between mixed and virtual reality. Originally, it was supposed that if participants were exposed to technology that was near the same level of media richness, there would still be an observed difference in collaboration due to the media naturalness theory. However, even though the only difference between conditions was the immersive environment, there were large discrepancies in environmental detail that could have skewed these results. For example, participants were represented in virtual reality by a grey body-shaped avatar consisting of block shapes, while participants in mixed reality looked as they do in real life with large headsets on their face and clunky remotes in their hands (See Appendix K). Obviously, general movements and gesturing may look significantly different in the two environments, but facial expressions were severely or entirely dampened in both. Considering the goal behind most communication technology is to increase face-to-face communication, both of these technologies seriously fell short of this goal because of its hindrance on natural communication. Kock (2004), in his proposition of media naturalness, identifies the five key elements of face-to-face communication: colocation, synchronicity, the ability to convey and observe facial expressions, the ability to convey and observe body language, and the ability to convey and listen to speech. While the ability convey and observe body language and synchronicity were different in mixed versus virtual reality, the headset technology used in this research prevented an critical deviation in participants' ability to convey and observe facial expressions. This shortcoming may have played a big role in the results of this study. Although the use of the same headset allowed for control in the study by avoiding confounding variables in the realm of headset differences, future research should consider the tradeoff between using the same headset for both environments to control for extraneous variables versus using headsets most appropriate for the environment. Potentially exploring augmented reality headsets, rather than mixed reality, may portray a more explicit difference in collaboration based on naturalness than a mixed reality headset. Because mixed reality, as identified in this study, sits between augmented and virtual reality considering naturalness, exploring augmented reality environments may be more appropriate when looking to understand collaboration differences based on media naturalness.

Limitations and Future Research

Limitations. Limitations of this research primarily lie in the methodology and technology used to complete the study. Outside of the low sample size, methodology could be improved in order to obtain clearer results from participants. During research sessions, it was never measured whether participants had experience in immersive technology before this study. The researcher did informally ask participants while setting them up in their environment, but data on this variable was never explicitly collected or measured. Another practice that may have biased results is participants' ability to see their teammate before and after the collaboration session, as well as their ability to hear and speak to each other without microphone or speaker assistance during the session. This could have skewed participants' perception of the immersive experience and therefore created potentially compromised results.

In relation to technology, the tools used in this research could have led to skewed measurements, as well as skewed collaboration. Concerning data collection, behavior data was only collected via sociometric badges. Upon data analysis this appeared to be a faulty tool, as five teams' data had to be dropped due to technical difficulties with these devices. In these instances, team data was dropped if no information was collected from either badge, or if the data was very obviously skewed (e.g., during one session, Participant 1's badge showed speaking for every second of the entire five-minute session while Participant 2's badge showed no speaking time data, which was known to be false because the recorded conversations showed no such extreme imbalance in speaking time). Other data collected via these badges could have been less skewed but still compromised, but there is little way of knowing because all behavior data was only collected via these sociometric badge tools. Another unfortunate fault of these devices' data collection is their inability to discern various kinds of inputs. For example, these badges recorded all speaking data from the participant wearing the badge, which includes any time a participant may have been speaking to themselves or under their breath. Even if a participant's comment did not contribute to the collaboration task or was not heard by the other participant, it was still counted as speaking data by their sociometric badge. Because these tools couldn't discriminate between valuable and meaningless data, it could have produced compromised results. Technology actively used by participants during the collaboration session could have also produced compromised results by influencing participant behavior. Specifically, the HMD technology used (HTC Vive Pro headsets) was restrictive and clunky, which prevented participants from moving freely and seamlessly as they do in reality. Wires on headsets made some students express an explicit inability to walk around the space as much as they wanted to, and hand-held controllers made some students express feelings of discomfort and hesitation for moving their hands during the session. Additionally, because of the size of this headset, it provided significantly different experiences for participants working in mixed reality or virtual reality. While participants in both conditions experienced the same tool to be immersed in their environment, the visual feedback when interacting with each other was significantly different regardless of realness in environment. Participants in virtual reality put on the headset and saw themselves and their partner as simple avatars made to represent how people look in the real world (See Appendix K). Participants in mixed reality put on the headset and saw their partner as they do in the real world but with a very large box covering a majority of their face. Because this box didn't exist in the virtual reality environment, it is possible that this factor caused participants to perceive their partner or participate in collaboration differently. Overall, limitations of this study primarily lie in methodological and technological shortcomings that should be remedied in future research.

Direction for Future Research. Because this research served as a pilot, it provided many directions for future research. Improving upon the limitations of this study, as well as opportunities for further growth are important to consider while researching collaboration in immersive technology.

Considering the practices of this study, there are opportunities to improve methodology and technology for the research following this pilot. On a basic level, recruiting more participants to draw data from a larger sample size will likely create stronger and more easily observable differences in behaviors and responses between conditions. Additionally, intentionally measuring participants' exposure to MR, VR, or other immersive technology prior to the study would allow researchers to consider and control for this variable. Another possibility for improvement lies in the lab environment set up and allowing participants to see each other outside of the collaboration environment. If exposure to other participants is hindered before and after the collaboration session, this might help support thinking of the immersive technology as a platform to mediate collaboration rather than just a tool to look at an image. Future research could also consider utilizing different headset technology to provide more similar visual experiences in viewing teammates. For example, utilizing MR technology that doesn't block as much of a participant's face, or VR renderings that show their avatar has a similar amount of their avatar face blocked as participants in MR. Making adjustments such as these could provide more of a fair comparison between the two conditions, however might not best service the question of naturalness between MR and VR. Because media naturalness requires such factors as the ability to observe facial expressions (Kock, 2004), the current MR technology does not satisfy this need. Future research should explore less clunky technology that provides participants with a more natural experience. Other tool improvements related to this research involve multi-tool measurements. Because there is the possibility for compromised behavior data because it was only recorded via sociometric badges, future research should consider collecting behavior data with multiple tools to ensure effective data collection. Making these slight modifications from this pilot to future research could allow for more clear insight about the differences in collaboration between

On a larger scale, future research on collaboration in immersive technology has the potential to help understand our relationships to each other through technology. The research conducted during this study shows how collaborating in immersive technology may not be significantly different across technology type. Because no significant differences were found in participant behavior, conversation, or experience between mixed reality and virtual reality, it is possible that successful technology-mediated interaction is not dependent on various advanced technological features once a certain level of features are reached (e.g., general body movement and clear speech communication). However, because this idea is not supported by various theories in the field (Daft & Lengel, 1986; Kock, 2004), it is likely that, based off this research, further exploration on collaboration in immersive technology is needed. Based on the limitations of this study, there are several directions future research could pursue to understand how various features of immersive technology impact team collaboration. Investigating such possibilities as measuring movement without hand controllers, or utilizing hologram technology to provide a technology-mediated collaboration experience without cumbersome headsets or wearable tools could allude to insights of human behavior and experience during technology-mediated teamwork. Hologram collaborative technology, such as Microsoft's Holoportation project, is not currently publicly available but serves as a possible next step in the exploration of collaborative immersive technology research. As technology continues to advance, research should follow to study what features help and hinder people working with each other through technology. With this continued exploration and development, we can work to provide opportunities for effective collaboration that will allow for a beneficial industrial work experience and provide a more effective workspace as industry working trends and technology evolve.

Conclusion

In summation, this research has presented a comparison between the media richness and media naturalness models through the lens of new and immersive technology. To test this comparison, a between-groups, simple, post-test only research design was implemented to observe how participants behaved, conversed, and experienced collaboration differently in mixed reality versus virtual reality environments. The difference in team collaboration between mixed reality and virtual reality was measured as teams of two participants engaged in a five-minute idea generation session based on the premise of environmental sustainability. The results of this research showed no significant difference in collaborative behavior, conversation, or experience between the two groups, indicating that media naturalness may not be as influential in collaboration success while media richness is held constant. Future research on this topic should continue to explore the difference in collaboration between immersive technologies such as these.

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APPENDIX A

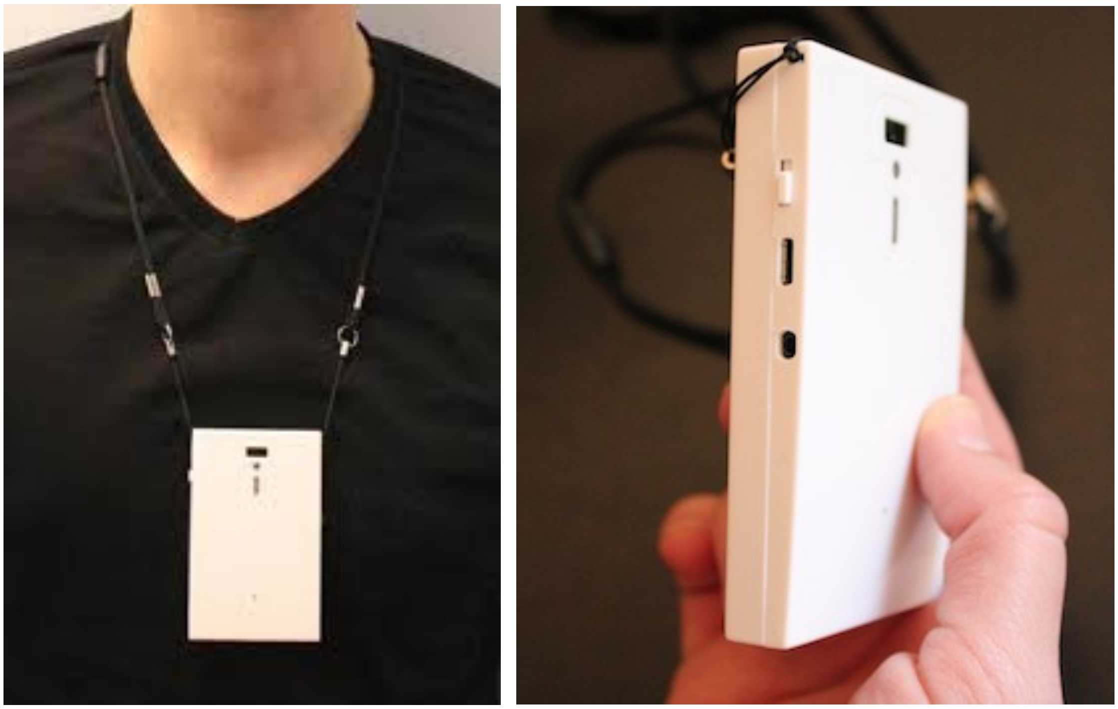
HTC Vive Headset and Handheld Remotes

HTC Vive Pro Headset participants wore during the collaboration task to immerse them in their assigned Mixed or Virtual Reality environment.

HTC Vive handheld remotes participants will hold during the collaboration task to control the hands of their avatar and for researchers to track participant movement. Remotes were covered in a protective sleeve to prevent participants from pressing buttons during the collaborative session.

APPENDIX B

Sociometric Badges



Sociometric badges will be worn around participants' necks for 5 minutes during the collaboration task in order to collect behavior data. Each badge is equipped with a 3-axis accelerometer, microphone, infrared transceiver, radio frequency, and Bluetooth module to measure motion, speech, face-to-face interaction, proximity, and location (Olguin & Pentland, 2008). In this study, data collected from the microphone and Bluetooth module will be used to understand participants' mimicry behavior, conversational balance, and proximity during the task.

APPENDIX C

Perceived Environmental Knowledge Scale

This scale was adapted by Mostafa (2007) with a reported *a* of 0,86. This scale will be used to understand participant's environmental knowledge in order to control for this potential confounding variable during data analysis.

Perceived Environmental Knowledge Scale

1. I know that I buy products that are environmentally safe.

1	2	3	4	5
Completely Disagree				Completely Agree

2. I know more about recycling than the average person.

1	2	3	4	5
Completely Disagree				Completely Agree

3. I know how to select products and packages that reduce the amount of waste ending up in landfills.

1	2	3	4	5
Completely Disagree				Completely Agree

4. I understand the environmental phrases and symbols on a product package

1	2	3	4	5
Completely Disagree				Completely Agree

5. I am very knowledgeable about environmental issues

1	2	3	4	5
Completely Disagree				Completely Agree

APPENDIX D

User Experience Questionnaire (UEQ)

The UEQ is a measure used to holistically understand users' impressions of a product, with reported sufficient reliability (Laugwitz et al., 2008). Participants are given this questionnaire in the study to measure their experience in VR or MR, and compare preferences between the two environments.

User Experience Questionnaire

Please rate your experience by filling in one circle per line.

	1	2	3	4	5	6	7	
Annoying	O	O	O	O	O	O	O	Enjoyable
Not Understandable	O	O	O	O	O	O	O	Understandable
Creative*	O	O	O	O	O	O	O	Dull
Easy to Learn*	O	O	O	O	O	O	O	Difficult to Learn
Valuable*	O	O	O	O	O	O	O	Inferior
Boring	O	O	O	O	O	O	O	Exciting
Not Interesting	O	O	O	O	O	O	O	Interesting
Unpredictable	O	O	O	O	O	O	O	Predictable
Fast*	O	O	O	O	O	O	O	Slow
Inventive	O	O	O	O	O	O	O	Conventional
Obstructive	O	O	O	O	O	O	O	Supportive
Good*	O	O	O	O	O	O	O	Bad
Complicated	O	O	O	O	O	O	O	Easy
Unlikable	O	O	O	O	O	O	O	Pleasing
Unusual	O	O	O	O	O	O	O	Leading Edge
Unpleasant	O	O	O	O	O	O	O	Pleasant
Secure*	O	O	O	O	O	O	O	Not Secure
Motivating*	O	O	O	O	O	O	O	Demotivating
Meets Expectations*	O	O	O	O	O	O	O	Does Not Meet Expectations
Inefficient	O	O	O	O	O	O	O	Efficient
Clear*	O	O	O	O	O	O	O	Confusing
Impractical	O	O	O	O	O	O	O	Practical
Organized*	O	O	O	O	O	O	O	Cluttered
Attractive*	O	O	O	O	O	O	O	Unattractive
Friendly*	O	O	O	O	O	O	O	Unfriendly
Conservative	O	O	O	O	O	O	O	Innovative

APPENDIX E

Modified Social Distance Questionnaire

The Social Distance Questionnaire is a measure used to understand how socially close a participant feels to the other participant. The questionnaire used in this study was modified from its original version for simplicity and ease cognitive load of participants.

Modified Social Distance Questionnaire

How well did you know your conversational partner before today?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

How strongly did you like your conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

How coordinated did you feel with your conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

To what extent did you feel that you and your conversational partner felt the same way?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

How well did you feel that you understood your conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

To what extent did you feel a sense of mutual agreement with you conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

To what extent did you feel that you and your partner were acting in unison?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

To what extent did you feel a sense of togetherness with your conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

How approachable was your conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

How friendly was your conversational partner?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

To what extent did you feel that the partner you saw in your headset resembled your partner in reality?

1	2	3	4	5
Not at all	Slightly	Fairly Well	Well	Close friend or relative

APPENDIX F

Modified Social Presence Questionnaire

The Social Presence Questionnaire is a measure used to understand how participants felt about the presence of their partner. The questionnaire used in this study was modified from its original version for simplicity and easy cognitive load of participants.

Modified Social Presence Questionnaire

I felt like the other participant was present

1	2	3	4	5
Not at all	Slightly	Moderately	Strongly	Very Strongly

I felt like I was in the same room with the other participant.

1	2	3	4	5
Not at all	Slightly	Moderately	Strongly	Very Strongly

I felt like the other participant was aware of my presence.

1	2	3	4	5
Not at all	Slightly	Moderately	Strongly	Very Strongly

I felt like the other participant was real.

1	2	3	4	5
Not at all	Slightly	Moderately	Strongly	Very Strongly

APPENDIX G

Researcher Study Script

This is the script the researcher read from while interacting with participants during the study. This script was strictly adhered to in order to provide all participants with the same information and avoid any potential researcher bias.

Computer Mediated Collaboration Script

Spring 2019

Pre-Study Checklist

1. Set up Steam VR and pull up files
    a. Open Steam & Steam VR
    b. Open files: File> This PC> DATA(D:)> CameronVRFiles> 2_20_datacap (unzipped)> 2_20_datacap> Female or Male CartoonVR or localAR
2. Turn on headset (blue button on link box) and controllers (small button at base of each controller handle)
3. Pull up survey (on goolge chrome, bookmarked “Cameron’s Survey”) and enter researcher information (participant ID number, condition, and badge number) then hit next on the survey and minimize window
4. Pull up slides and full screen
    a. Open slides: File> This PC> DATA(D:)> CameronVRFiles> Task Pres pdf

5. Set up microphone for conversation recording
    a. Open voice recorder on third laptop
    b. Plug in microphone via USB port
    c. Microphone set up to start recording:
        i. AUDIO I/F
        ii. CONNECT

        *Scroll and select via the side "PLAY" toggle
    d. Test microphone to ensure working properly
6. Make sure each station has:
    a. 1 headset
    b. 2 controllers
    c. 2 control covers
    d. 1 sociometric badge
    e. 1 consent form
    f. 1 pen

Introduction

Hi, what's your experiment ID?

[Check to make sure we have the right participant]

Welcome to the study, we'll be working in here today.

[Direct to desk in room]

If you could completely tuck your stuff under this desk, make sure your phone is off or not on your person, then sit over here and read and sign the informed consent form.

Please read it carefully. Also, please don't touch anything on your desk other than the paper and pen at this time.

This study is NOT for people who are: under 18, prone to motion sickness or other similar balance and dizziness conditions, as well as people who are pregnant, have had a recent concussion, seizure disorder, history of fainting or seizures, visual impairment, hearing disabilities, or any other condition that makes someone prone to dizziness or disorientation. If you have any of these symptoms, you are NOT eligible to participate in this study. Are there any questions of concerns about this?

[if one or both of the participants express concerns about their health situations or have injuries, give both of the participants credit and let them leave. Make a note of this in log]

Thank you for finishing the consent form. Sorry that I have to read from this script because I want to make sure I give every participant the same information

Headset and Task

Today you will be interacting with each other in [MIXED / VIRTUAL REALITY] to complete a task. After you complete the task, you will complete a brief questionnaire about your experience then you will be free to leave.

[Read from below paragraph according to appropriate environmental condition]

[MR]

Working in mixed reality means you will be wearing a headset and holding two hand-controllers. With this headset you will be able to see our current room [gesture to room] with a virtual image in it. Keep in mind that when you are looking around with the headset on, the camera or controllers may slightly lag, which may cause a little disorientation. I will be in the room the entire time you are wearing your headsets to help avoid tripping or lag-related accidents.

[VR]

Working in virtual reality means you will be wearing a headset and holding two hand-controllers. With this set up you will be able to control an avatar in a virtual space, made to look similar to this room. Keep in mind that when you are looking around with the headset on, the dimensions of the virtual room may be slightly different from this room and cause a little disorientation. I will be in the room the entire time you are wearing your headsets to help avoid tripping or other accidents.

You are going to complete a collaborative task that will help us look at mediated interaction. You will now read through the presentation on your computer to understand your task. Please pay attention as your success depends on this information.

[wait for students to finish slides]

Great job. Can you guys describe to me what you're supposed to do?

[wait for response]

[If participants are unclear on task, be sure to specify:

1. Create sustainability ideas for the company
2. Do not repeat examples from the 15 principles
3. They will have 5 minutes to talk to each other about the task]

Fantastic

Do you have any questions?

[wait for response]

Set up

Now I will get you both set up in your environment so you can start your task. Once you have your headset on, you are free to wander around the space as you wish. I will be watching to help avoid accidents.

Please put the white badge around your neck, and adjust the strap so that the white rectangle is on your chest immediately below your chin. If you need help, just let me know. These will not be on yet, I will turn them on as soon as your task starts.

Next I will help you put your headset on and place you in the room. Please don't press any buttons on your hand controllers. Feel free to look around and explore the space. You can move through out the room, but don't begin discussing the task until I say to begin.

[1. Right desk: As participant to stand and tuck in chair

2. Pull up environment

3. Put on headset (assist participant if needed)

4. Give hand controllers (make sure they have the covers on)

5. Ask them to turn around and face the front door of the lab

6. "Do you see an image near the door where you walked in?" (Wait for a response)

7. Stand in front of door "Can you take a few steps [MR] towards me [VR] towards the sound of my voice?" (wait for participant to move)

8. "Great, you can see in the space, you can move in the space, and you're good to go! Feel free to explore the room while I set up your partner"]

[1. Left desk: Ask participant to stand and tuck in chair

2. Pull up environment

3. Put on headset (assistant participant if needed)

4. Give hand controllers (make sure they have the covers on)

5. Ask them to turn around and face the front door of the lab

6. "Do you see an image near the door where you walked in?" (Wait for a response)

7. Stand in front of door "Can you take a few steps [MR] towards me [VR] towards the sound of my voice?" (wait for participant to move)

8. "Great, you can see in the space, you can move in the space, and you're also good to go!"]

Ok, I am now going to turn on your badges [Turn on badges- 69 first then 71]

Your time is about to start. When you're working on your task, you may address your partner, move throughout the space, and reference the image at your own discretion. Please pretend I'm not in the room and do not reference me while you're working. Just as a reminder, your job now is to generate as many sustainability ideas for this company as possible. Do you have any questions?

[Answer questions if participants ask]

[Start stop watch and voice recording, and begin]

Your time starts now, you have 5 minutes to complete your task

[make a note of the time participants start talking to use in session duration settings for Sociometric DataLab later]

Post Task

Your time is up! I will come and turn off your badges and take your hand remotes. Please take off your headsets and find your seats. I will now pull up a quick survey for you to complete individually on the computers at your desk. Please take your time and be thoughtful in your responses. Once you're done, grab your things from under the side desk and stop by my desk outside of the room before you leave.

[pull up survey and enter participant ID and setting]

Thank you so much for taking part in my research! Do you feel any dizziness or motion sickness like symptoms?

> If yes… Please take a seat and relax until you feel better. I want to make sure you're feeling back to normal before you leave

Do you have any questions?

[Answer any questions participants may have about the research]

I will make sure to award you your credit on SONA, which may take 1-2 days to show up. If you don't see these credits by this time next week, please shoot me an email and I'll make sure to take care of it. Have a nice day!

Post-Study Checklist

1. Collect informed consent forms and sociometric badges
2. Download badge information into Sociometric DataLab

3. Move movement data
    a. Find movement data in File> This PC> DATA(D:)> CameronVRFiles> 2_20_datacap (unzipped)> 2_20_datacap> Recording
    b. Rename data to match participant ID and CTRL+C
    c. Go to File> Dropbox> Synchrony2> CameronVRFiles> Movement_Data
    d. Create a new folder with session ID
    e. CTRL+V movement data into new folder
4. Save recording data to be transcribed later, rename to match session ID
5. Administer SONA credits to participants
6. Reset room for next session following pre-study checklist

APPENDIX H

Task Introduction Presentation

This presentation was an introduction to the task participants were being asked to partake in during the study. It was presented in full-screen mode on a laptop and participants could advance through the slides by clicking the mouse or arrows on the keyboard.

IMAGINE...

Imagine you are part of a conservation-consulting firm trying to gain the business of a company who is looking to becoming more environmentally conscious. The business was built on three main values:

- remaining profitable
- serving their customers
- Encouraging healthy lifestyles for all their employees

2

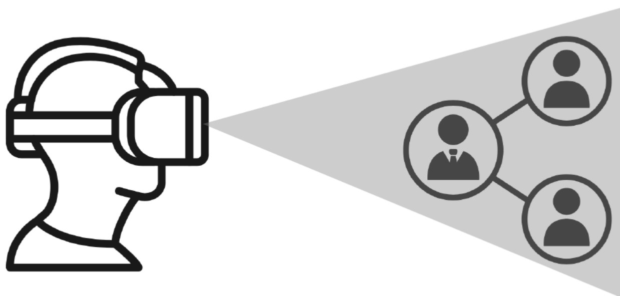
TASK

You and your teammate have 5 minutes to develop as many potential ideas to **increase sustainable practices**, especially those related to water and energy conservation, for this company as possible

Your results will be compared to other teams to determine which team will be hired for the project. The success of your team will be judged based on **creativity** and **quantity** of ideas you develop.

3

BUSINESS ORGANIZATION



With your headset on, you will be able to see a general organization of this business (your potential client). This image may help you identify areas to increase sustainable efforts for the company, but you are not required to reference it.

4

15 ENVIRONMENTAL PRINCIPLES

To help you develop ideas, 15 environmental principles related to water use are listed below. You do NOT have to memorize these, as they are just a few ideas to help you generate your own.

Please read them carefully because in order for your team to be successful, you should try to avoid repeating these ideas.

5

1. Avoid using water entirely when other methods are possible

For example, don't use a power-washer or hose to clean the walkway in front of your retail store when you can sweep instead.

6

2. Plan ahead to avoid having to use or heat water unnecessarily

For example, when preparing lunch in your office, instead of running hot water on frozen vegetables to thaw them, defrost items overnight in the refrigerator.

7

3. Spend money on businesses that use water/ energy in efficient ways. Not only does this save water in itself, but it also encourages other businesses to follow eco-friendly practices

For example, when looking for factories to source your materials from, choose one that recycles its water during the manufacturing process.

8

4. Heat water in the most energy efficient way. You want to make sure that as much as possible of the energy you use is going directly to heating the water that you want to use, and only that water

For example, switch to a tankless water heater in your office building rather than a water tank that will heat water the office may not use before it cools.

9

5. Do not use bottled water

In the U.S., tap water is safe to drink. So using bottled water wastes energy both in packaging and transport. Provide all employees with a reusable water bottle to save energy.

6. Try to use water in ways appropriate for the time of day

For example, it's often against city regulations to water the lawn or grounds of your office when its hot out, because water will evaporate quickly and it's wastefully ineffective.

7. Avoid using products that require a lot of water to produce

For example, a lot of water is used to raise animals for meat. Therefore, encouraging Meatless Mondays (or other meat consumption reduction strategies) in your office is a good way to save water.

12

8. Stop water from leaking out of the system

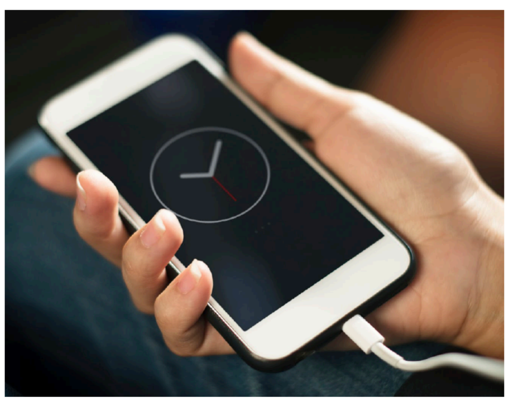
For example, fixing a leaky pipe in your factory would save water and also prevent an unnecessary expense.

13

9. Turn off appliances that use or heat water when you don't need them. This will prevent unknowing energy or water use.

For example, when you are closing your retail store for the night, it is a good idea to turn off your water heater while you are gone, since otherwise you will be wasting energy keeping water hot for no one to use.

14



10. Keep track of water use. If you monitor the volume of water you are using, you can be more careful about conservation

For example, you could encourage employees to use a timer while they are in the shower in order to be mindful about the amount of water they're using.

15

11. Be careful not to pollute natural waterways, since this is water that may need to be used again

For example, do not pour manufacturing chemicals directly into drains or sewers because this will pollute and waste the water into which it flows.

16

12. Reuse water whenever possible

For example, you can collect water used in manufacturing and use it for toilet water or to water surrounding vegetation.

17

13. Do not use more water than is necessary for a given task

For example, in your factory, find a different way to cool your machines than water.

18

14. Use economy settings on appliances. Many modern appliances have energy or water-sparing settings

For example, dishwashers in the office can be set to use less water or less hot water by simply pressing a button.

19

15. Minimize your use of hot water

For example, washing retail store floors and counters in warm or cold water instead of hot water can save energy.

20

REMEMBER

Your task now is to work with your teammate to create as many sustainability ideas for the company (your potential future client) as possible.

You will have 5 minutes to develop these ideas in order to gain the business of this potential client.

21

End of Introduction

Please sit quietly and wait for future instruction from the researcher before proceeding.

22

APPENDIX I

Behavior, Conversation, and Reported Experience Correlational Matrix

	Mirror Volume	Mirror Frequency	Mirror Body	Speaking (min 1)	Speaking (min 2)	Speaking (min 3)	Speaking (min 4)	Speaking (min 5)	Speaking Total
Mirror Volume	1	.570** (.000)	.091 (.566)	.101 (.525)	.072 (.650)	.158 (.317)	.099 (.534)	.106 (.506)	.142 (.370)
Mirror Frequency	.570** (.000)	1	.212 (.178)	-.024 (.880)	.105 (.509)	.110 (.489)	.079 (.620)	.138 (.382)	.107 (.499)
Mirror Body	.091 (.566)	.212 (.178)	1	-.198 (.209)	-.091 (.565)	-.121 (.445)	-.189 (.231)	-.077 (.628)	-.182 (.249)
Speaking (min 1)	.101 (.525)	-.024 (.880)	-.198 (.209)	1	.452** (.003)	.374* (.015)	.576** (.000)	.292 (.060)	.744** (.000)
Speaking (min 2)	.072 (.650)	.105 (.509)	-.091 (.565)	.452** (.003)	1	.534** (.000)	.622** (.000)	.419** (.006)	.822** (.000)
Speaking (min 3)	.158 (.317)	.110 (.489)	-.121 (.445)	.374* (.015)	. 534** (.000)	1	.431** (.004)	.245 (.119)	.671** (.000)
Speaking (min 4)	.099 (.534)	.079 (.620)	-.189 (.231)	.576** (.000)	.622** (.000)	.431** (.004)	1	.382* (.012)	.805** (.000)
Speaking (min 5)	.106 (.506)	.138 (.382)	-.077 (.628)	.292 (.060)	.419** (.006)	.245 (.119)	.382* (.012)	1	.648** (.000)
Speaking Total	.142 (.370)	.107 (.499)	-.182 (.249)	.744** (.000)	.822** (.000)	.671** (.000)	.805** (.000)	.648** (.000)	1
Proximity	.033 (.835)	-.147 (.354)	-.403** (.008)	-.022 (.888)	.230 (.142)	.223 (.155)	.174 (.270)	.069 (.666)	.173 (.274)
Convo Score	-.064 (.686)	.133 (.401)	-.163 (.302)	.109 (.492)	.059 (.710)	-.018 (.909)	.006 (.972)	-.176 (.265)	-.003 (.984)
Social Distance	.171 (.279)	-.041 (.794)	-.102 (.521)	-.149 (.345)	-.059 (.709)	.009 (.956)	-.041 (.796)	-.057 (.719)	-.087 (.582)
Social Presence	.148 (.348)	.126 (.425)	-.023 (.883)	-.163 (.302)	-.154 (.330)	-.089 (.575)	-.159 .314	-.432** (.004)	-.278 (.074)
UEQ Factor 1	-.115 (.469)	-.428** (.005)	-.113 (.474)	-.004 (.981)	-.087 (.583)	.045 (.780)	-.077 (.630)	.071 (.655)	-.014 (.928)
UEQ Factor 2	.036 (.821)	.355* (.021)	-.114 (.473)	.035 (.824)	.268 (.086)	.330* (.033)	.150 (.343)	.170 (.281)	.249 (.111)
UEQ Factor 3	-.033 (.834)	-.140 (.376)	.043 (.787)	.148 (.350)	-.076 (.634)	-.250 (.110)	.086 (.587)	-.062 (.696)	-.031 (.844)
UEQ Factor 4	-.125 (.429)	-.199 (.208)	-.129 (.417)	-.213 (.175)	-.225 (.151)	-.059 (.709)	-.060 (.707)	-.093 (.558)	-.186 (.238)
UEQ Factor 5	.248 (.113)	.307* (.048)	.144 (.362)	.127 (.422)	.136 (.390)	.048 (.762)	.399** (.009)	.241 (.124)	.255 (.104)
UEQ Factor 6	-.115 (.469)	-.4288** (.005)	-.113 (.474)	-.004 (.981)	-.087 (.583)	.045 (.780)	-.077 (.630)	.071 (.655)	-.014 (.928)

Proximity	Convo Score	Social Distance	Social Presence	UEQ Factor 1	UEQ Factor 2	UEQ Factor 3	UEQ Factor 4	UEQ Factor 5	UEQ Factor 6
.033 (.835)	-.064 (.686)	.171 (.279)	.148 (.348)	-.115 (.469)	.036 (.821)	-.033 (.834)	-.125 (.429)	.248 (.113)	-.115 (.469)
-.147 (.354)	.133 (.401)	-.041 (.794)	.126 (.425)	-.428** (.005)	.355* (.021)	-.140 (.376)	-.199 (.208)	.307* (.048)	-.428** (.005)
-.403** (.008)	-.163 (.302)	-.102 (.521)	-.023 (.883)	-.113 (.474)	-.114 (.473)	.043 (.787)	-.129 (.417)	.144 (.362)	-.113 (.474)
-.022 (.888)	.109 (.492)	-.149 (.345)	-.163 (.302)	-.004 (.981)	.035 (.824)	.148 (.350)	-.213 (.175)	.127 (.422)	-.004 (.981)
.230 (.142)	.059 (.710)	-.059 (.709)	-.154 (.330)	-.087 (.583)	.268 (.086)	-.076 (.634)	-.225 (.151)	.136 (.390)	-.087 (.583)
.223 (.155)	-.018 (.909)	.009 (.956)	-.089 (.575)	.045 (.780)	.330* (.033)	-.250 (.110)	-.059 (.709)	.048 (.762)	.045 (.780)
.174 (.270)	.006 (.72)	-.041 (.796)	-.159 (.314)	-.077 (.630)	.150 (.343)	.086 (.587)	-.060 (.707)	.399** (.009)	-.077 (.630)
.069 (.666)	-.176 (.265)	-.057 (.719)	-.432** (.004)	.071 (.655)	.170 (.281)	-.062 (.696)	-.093 (.558)	.241 (.124)	.071 (.655)
.173 (.274)	-.003 (.984)	-.087 (.582)	-.278 (.074)	-.014 (.928)	.249 (.111)	-.031 (.844)	-.186 (.238)	.255 (.104)	-.014 (.928)
1	.046 (.773)	.376* (.014)	.210 (.183)	.157 (.320)	.039 (.808)	-.291 (.062)	.072 (.651)	.064 (.688)	.157 (.320)
.046 (.773)	1	-.015 (.915)	.117 (.407)	-.178 (.206)	-.179 (.205)	-.034 (.812)	.120 (.397)	-.094 (.508)	-.178 (.206)
.376* (.014)	-.015 (.915)	1	.443** (.001)	-.062 (.665)	.086 (.542)	.009 (.952)	.076 (.592)	-.043 (.762)	-.062 (.665)
.210 (.183)	.117 (.407)	.443** (.001)	1	-.390** (.004)	.198 (.159)	-.142 (.315)	-.013 (.927)	.122 (.388)	-.390** (.004)
.157 (.320)	-.178 (.206)	-.062 (.665)	-.390** (.004)	1	-.125 (.378)	.039 (.783)	.488** (.000)	-.122 (.388)	1.000** (.000)
.039 (.808)	.179 (.205)	.086 (.542)	.198 (.159)	-.125 (.378)	1	-.278* (.046)	-.064 (.652)	.193 (.171)	-.125 (.378)
-.291 (.062)	-.034 (.812)	.009 (.952)	-.142 (.315)	.039 (.783)	-.278* (.046)	1	.089 (.532)	-.150 (.287)	.039 (.783)
.072 (.651)	.120 (.397)	.076 (.592)	-.013 (.927)	.488** (.000)	-.064 (.652)	.089 (.532)	1	-.044 (.757)	.488** (.000)
.064 (.688)	-.094 (.508)	-.043 (.762)	.122 (.388)	-.122 (.388)	.193 (.171)	-.150 (.287)	-.044 (.757)	1	-.122 (.388)
.157 (.320)	-.178 (.206)	-.062 (.665)	-.390** (.004)	1.000 (.000)	-.125 (.378)	.039 (.783)	.488** (.000)	-.122 (.388)	1

***- Correlation is significant at the 0.01 level (2-tailed).*
**- Correlation is significant at the 0.05 level (2-tailed.*
UEQ Factor 1- Perspicuity, UEQ Factor 2- Attractiveness, UEQ Factor 3- Dependability, UEQ Factor 4- Efficiency, UEQ Factor 5- Stimulation, UEQ Factor 6- Novelty

APPENDIX J

Participant Demographics

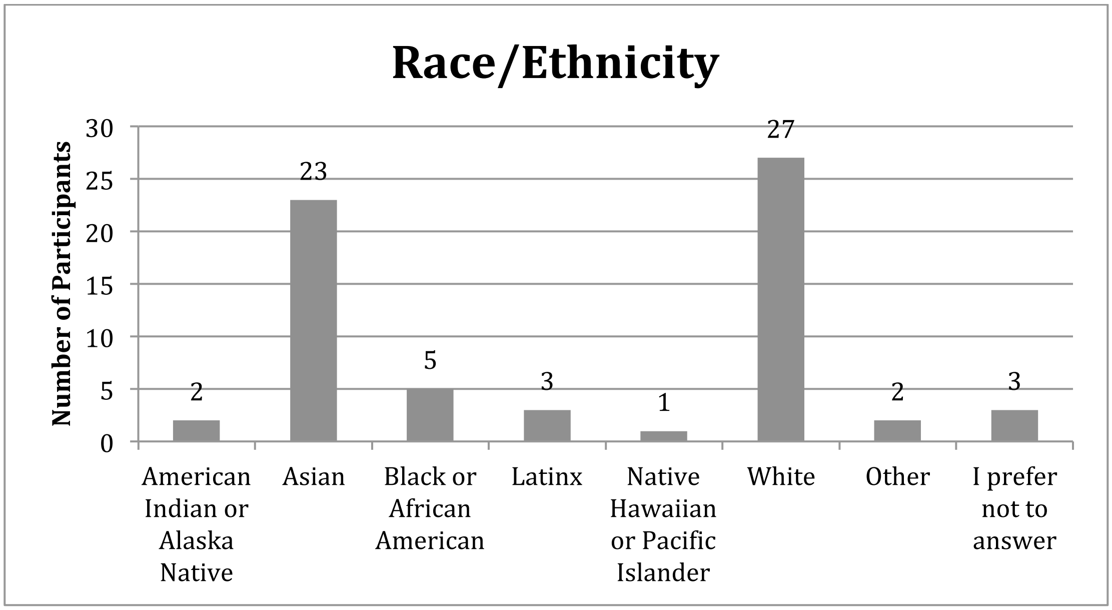


Figure 11. *This graph shows the distribution of participants' reported nationalities. This data was collected during the post-task survey.*

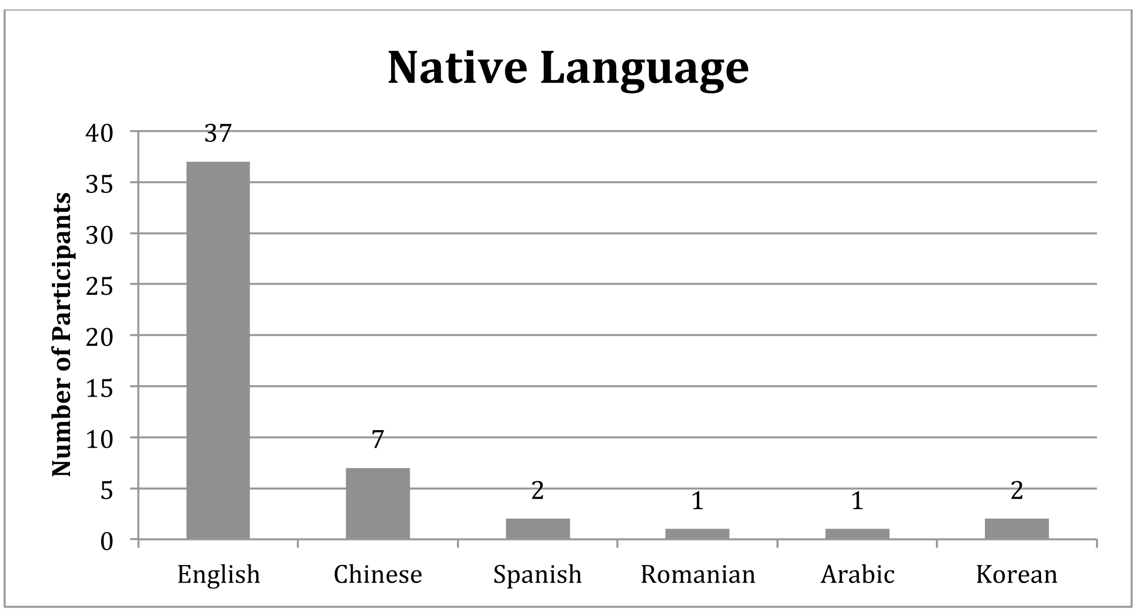


Figure 12. *This graph shows the variety of participants' reported native languages. This data was collected during the post-task survey.*

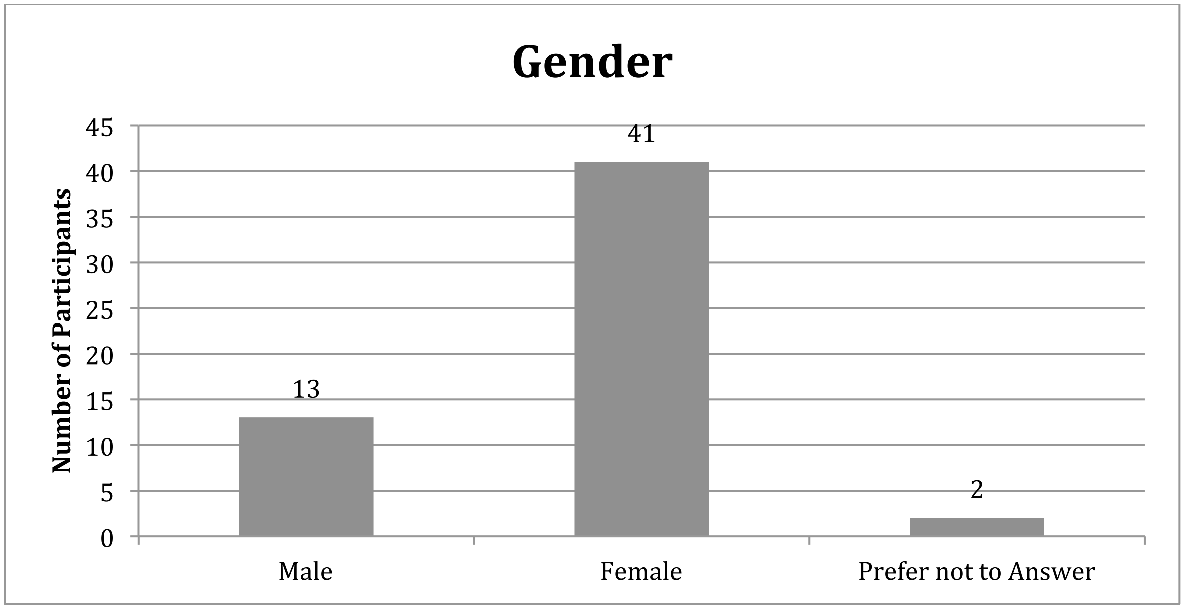
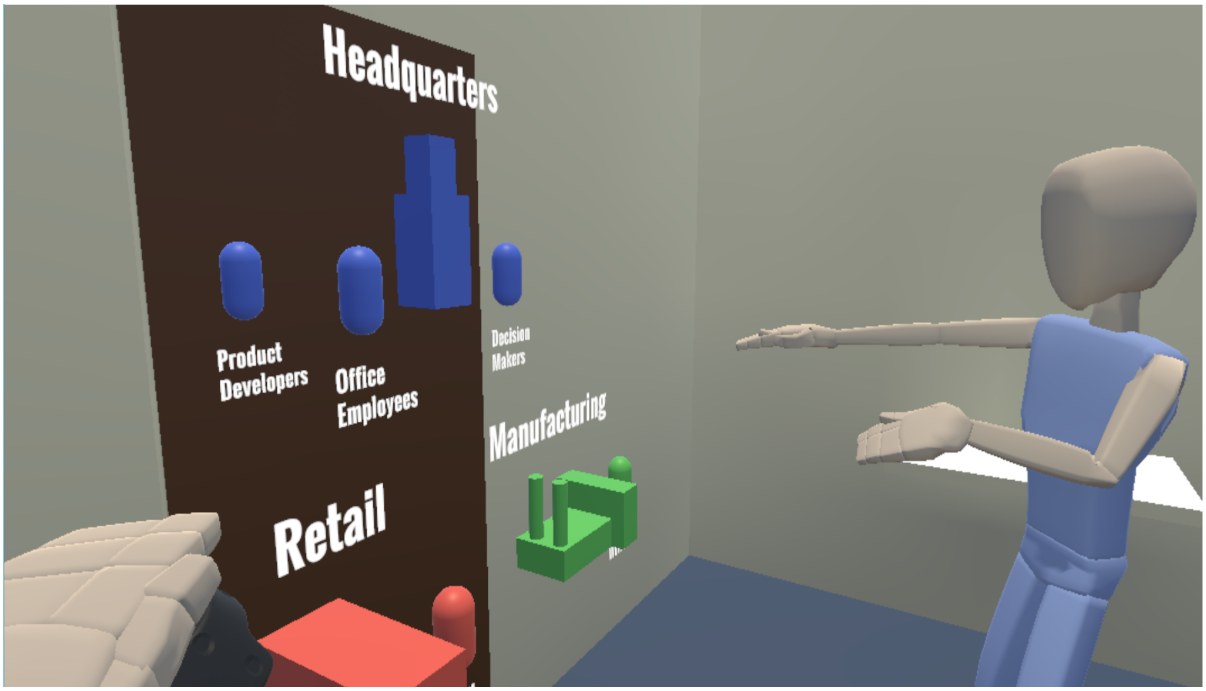


Figure 13. This graph shows the variety of participants' reported gender identity. This data was collected during the post-task survey.

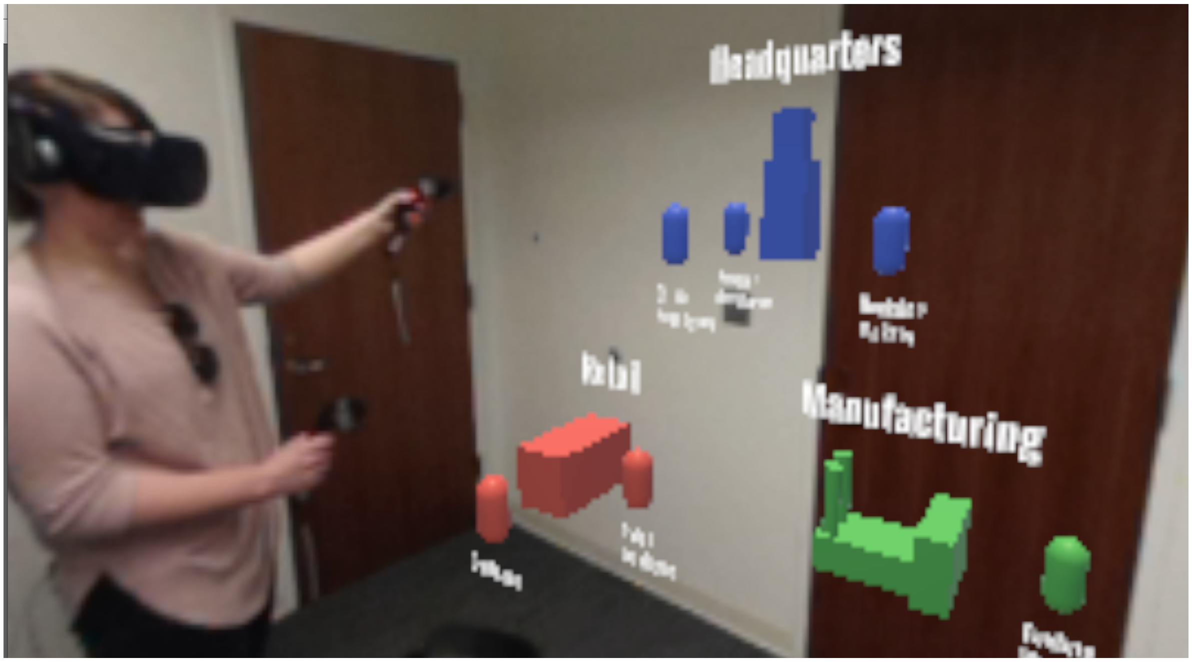
APPENDIX K

Team in Environments

Dyad's collaborated via HMD's that allowed them to work in mixed or virtual reality. Participants wore HMD's, held two hand controllers, and hung sociometric badges around their necks. Participants could speak and move freely in this environment with a researcher standing in the corner of the room to ensure safe interaction.



Teams working in virtual reality were immersed in the environment shown above. Individuals were represented by avatar, which they could control by moving they head and hands throughout the space. The VR environment was rendered to look similar to the lab room in reality, with a task-related image portrayed in the space. The image remained stationary in the environment, and could not be moved or manipulated by participants.



Teams working in mixed reality were immersed in the environment shown above. Individuals could see themselves and their partners as they do in reality, with the rendered image portrayed in the space. The image was anchored on a side of the room near the entrance, and could not be moved or manipulated by participants.