Designing Virtuoso: A Case Study on the Interdisciplinary Development of a Multi-User Virtual Reality Intervention for Individuals with Autism

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Thank you for reviewing my paper. I appreciate any generalized feedback that you have on the manuscript. I am also eliciting feedback concerning these four areas 1) Description of methods (is it clear how this was done), 2) Alignment with the theme of the symposium and book, 3) The Case Narrative that I provide (is this too much detail or is it helpful to have this much insight into our process), and 4) Importance to the field (how we can strengthen the Lessons Learned). Thank you so much and I will see you in Bloomington!

Multi-User Virtual Environments (MUVE) are graphically detailed three-dimensional digital environments that are designed to promote collaborative, user-centric learning opportunities (Churchill & Snowdon, 1998). In MUVEs, users take on humanoid avatars that act as digital representations of self as they interact with the virtual world and participate in programmatically scripted events. MUVEs vary in sophistication along dimensions of world design, embodied representation of users, interactivity, sensory perception, and controls (Ibáñez et al. 2013). They also hold a variety of affordances that make them ideal tools for providing controlled scenarios that can promote learning and assessment (Dalgarno & Lee, 2010). In particular, the affordances of virtual reality also appear to be well aligned with the learning needs of nontraditional learners like those with disabilities such as autism (Conway, Vogtle, & Pausch, 1994; Strickland, 1997; Dalgarno & Lee, 2010; Parsons, 2016; Glaser & Schmidt, 2018). However, creating MUVE requires a vast and interdisciplinary team of educators, researchers, content experts, programmers, 3D modelers, designers, developers, and more. Thus, creating a MUVE is a remarkably difficult task for educational technologists (Bricken, 1994; Bartle, 2004; Hirumi, Appelman, Rieber, & Van Eck, 2010). This challenge is further amplified when designing MUVE for individuals with autism, who exhibit substantial variability in the unique challenges that they face (Parsons, 2016).

Autism spectrum disorder (ASD) is a lifelong diagnosis that manifests as pervasive social and communicative difficulties coupled with inhibiting, stereotyped, and repetitive behaviors. Recent studies indicate that one in 59 individuals in the United States have an ASD diagnosis (Christensen et al., 2018). Autism is a spectrum disorder (Wing, 1996), with its diagnosis being composed of a series of impairments around social, communicative, and cognitive abilities (Wing & Gould, 1979). In addition to persistent socio-communicative and behavioral deficits, individuals with autism tend to present a variety of comorbid disorders including additional cognitive impairments, anxiety disorders, sensory processing problems, and more (Simonoff et al. 2008). Deficits resulting from an ASD diagnosis can severely impact an individual’s quality
of life and ability to function in an independent manner. If left untreated, these problems can become exacerbated and can lead to social isolation, difficulty maintaining relationships, and hardships with finding meaningful employment (Frith & Mira, 1992; Eaves & Ho, 2008).

Despite decades of research, social, communicative, vocational, and accommodation-related outcomes for adults with ASD remain poor (Billstedt, Gillberg, & Gillberg, 2005; Eaves & Ho, 2008; Howlin, Goode, Hutton, & Rutter, 2004; Parsons, 2016). To assist in reducing uncertainty of outcomes, The National Standards Project outlined intervention guidelines and pushed for evidence-based practices in the field (Wilczynsky, 2010). The National Professional Development Center on Autism Spectrum Disorder (NPDC) has also detailed evidence-based practices that can be implemented in behavioral interventions for individuals with autism (Bogin, 2008) and have advocated for technology-aided instruction.

One technology that has been considered as potentially efficacious with this population is virtual reality (VR). Interest in virtual reality technologies for individuals with ASD has been growing for decades (Aresti-Bartolome & Garcia-Zapirain, 2014) as researchers are increasingly turning to VR as a means to provide both therapeutic and educational platforms for individuals with ASD. This trend is due in part to evidence that suggests VR is intrinsically reinforcing for people with ASD, who find the technically and visually stimulating nature of the technology to be appealing (Schmidt et al., 2019). VR platforms also have a variety of technological affordances which align with the instructional needs of this population (Glaser & Schmidt, 2018). These benefits include the predictability of the task, ability to control system variables and complexities, realism of digital assets, immersion, automation of feedback, assessment, reinforcement, and more (Bozgeyikli, Raij, Katkoori, & Alqasemi, 2018; Bozgeyikli et al., 2018).

For instance, VR is capable of conveying concepts, meanings, and activities through high fidelity digital worlds that can emulate the real world. Therefore, authentic virtual scenarios can provide a meaningful context to embody and practice behaviors and skills (Wang, Laffey, Xing, Ma, & Stichter, 2016; Wallace, Parsons, & Bailey, 2017). Current research suggests that MUVE have potential to promote the acquisition of social, communicative, and adaptive competencies for individuals with ASD (Parsons, 2016; Glaser & Schmidt, 2018; Schmidt et al., 2019). This research has provided a preliminary basis of support for VR as an intervention modality for individuals with ASD (Mesa-Gresa, Gil-Gómez, Lozano-Quilis, & Gil-Gómez, 2018). Our project, entitled Virtuoso (a play on the words “virtual” and “social”), is an MUVE that was developed to promote adaptive competencies for individuals with ASD. We discuss Virtuoso in the following section.

Project Description
Virtuoso is a MUVE that was developed for participants in an autism adult day program called *Impact Innovations*. One of the goals of the *Impact Innovations* program is to provide participants with vocational opportunities that are oftentimes geographically distant from campus. With transportation being one of the most cited barriers to access community settings for individuals with disabilities (Allen & Moore, 1997; Carmien, et al., 2005), the focus of Virtuoso is promoting adaptive skills related to using a university shuttle public transportation system. To this end, we designed a virtual reality curriculum based on a detailed task analysis using procedural analysis techniques (Jonassen, Tessmer, & Hannum, 1998). This process provided guidance on activity structure that needed to be designed and provided by the VR environment.

Creating a MUVE that could fulfill the requirements and needs of our curriculum required vast interdisciplinary expertise. For instance, skills that were required included graphical design, 3D modeling, visual scripting, object-oriented programming, computer hardware, learning theory application, photography, computational thinking, and even drone piloting. These skills were brought to the fore both proactively and in an emergent manner. For instance, we formed our core team with individuals who had expertise in many disciplines including special education, applied behavior analysis, engineering, geography, instructional design, educational game design, mobile learning, information technology, computer science, etc. Further, Virtuoso was developed using an open-source platform (High Fidelity: https://www.highfidelity.com/), which we chose because it allowed a small design team to leverage a vibrant development community, thus providing opportunities to collaborate and engage with individuals working to solve similar problems in their own projects. Using open-source software also made possible deep modification of the platform through custom scripting and community-provided plugins, thereby allowing us to extend the functionality of the system to meet the needs of our project.

The Virtuoso MUVE was informed by the literature, which provided guidance in the form of design principles. Specifically, we sought principles that could help promote the transfer of adaptive skills from the virtual environment to the real-world for individuals with autism. In order to promote transfer, the literature suggests providing tasks that are capable of embodying users within the learning process (Mennecke, Tripplett, Hassall, & Conde, 2010). Research suggests that when users are able to feel immersed and a sense of embodiment of self and others in a collaborative virtual space, then the tasks they engage with can take on a deeper meaning (Mennecke, Tripplett, Hassall, & Conde, 2010). In addition, VR technologies may help to convey meanings and symbolic measures of real world activities (Wang, Laffey, Xing, Ma, & Stichter, 2016; Wallace, Parsons, & Bailey, 2017) that can be enhanced through behavioral and visual realism of in-world assets (Parsons, 2016). A key premise that supports these claims is the
assumption of veridicality, which maintains that if VR experiences are sufficiently authentic and realistic, people will interact with and respond similarity in the digital world as they do in the real world, which arguably can promote transfer from the prior to the latter (Parsons, 2016; Yee, Bailenson, Urbanek, Chang, & Merget, 2007).

**Methodology**

The current research is presented here as an instrumental case study (Stake, 1994), that is, the examination of a specific case (person, group, department, or organization) with the purpose of providing insight into an issue, to redraw generalizations, or to build theory (Stake, 1995). The issue we focus on here relates to the assumption of veridicality and the premise that the realism provided by VR potentially can promote transfer of skills from a VR environment to the real world for individuals with autism. At issue is that there is a substantial research to practice gap on how designers can bring this principle to life. It is therefore the purpose of this case study to provide insight into the complexities of design and development of a MUVE for individuals with autism called Virtuoso that took place at a large midwestern university, with a particular focus on the interdisciplinary nature of the research and development. This case study specifically examines the intricacies of imbuing realism and authenticity into a virtual public transportation simulation with the purpose of promoting transfer of skills for individuals with autism.

Stake’s (1995) characterization of case study calls for flexibility in design so that researchers can make changes even after they proceed from design to research (Yazan, 2015). Due to the nature of this flexibility, the exact point when data collection begins can be hard to determine leading to sampling often being re-strategized (Stake, 1995; Yazan, 2015). Instrumental case study is an appropriate method for the current inquiry, as it allows researchers to “use issues as conceptual structure in order to force attention to complexity and contextuality, [and] because issues draw us toward observing, even teasing out, the problems of the case, the conflictual outpourings, the complex backgrounds of human concern” (pp. 16-17). The complexities of developing Virtuoso required our small development team to develop our own interdisciplinary set of skills and expertise to solve this design problem, as well as seeking interdisciplinary expertise externally. This instrumental case study attempts to chronicle our design processes by exploring our particular research and development trajectory in depth. Although it is generally accepted that developing VR interventions in the field of autism research is fraught with challenges, very little has been written to chronicle those challenges and how they were approached. Therefore, it is our hope that, with this case study, others in the field will be able to extrapolate lessons learned and apply our solutions to their own design and development challenges.

**Key Participants**
Since 2015, an interdisciplinary team of researchers have designed and developed Virtuoso in collaboration with *Impact Innovation*. This case study focuses specifically on those members of the team who were members of the instructional design studio engaged in the process of developing the intervention. These three individuals were males, including: (1) one instructional design and technology professor, (2) one instructional design and technology PhD student, and (3) one engineering undergraduate student. All team members were directly involved in the design and development of Virtuoso over a 2.5 year period. Our team had expertise in information technology, software development, development of virtual worlds, and educational game design.

**Data Collection**

Case study data are characterized as the lived experiences of the first author, an instructional design and technology PhD student, relative to his deep involvement in the design and development of the intervention. These experiences were assembled after a fully functional prototype of the intervention had been created using autoethnographic methods (Bruner, 1993; Freeman, 2004) in which project artifacts were consulted to assist with recall (Goodall, 2001). Artifacts included screenshots, 3D digital assets, video recordings, procedural analysis documents, team meeting minutes, team communications (e.g., emails, instant message transcripts), rapid prototypes versions, and project documentation. Project artifacts were organized based on the overarching theme of imbuing authenticity and realism into the MUVE and how this was achieved relative to each asset or virtual element that was reviewed. This process led to four categories of artifacts being identified: (1) developing a realistic terrain, (2) developing realistic campus buildings, (3) developing realistic interiors, and (4) developing realistic scenarios. After organizing project artifacts into these four categories, their development was then mapped out onto individual timelines to provide a linear representation of the research and development process.

Next, autoethnographic methods were used to make sense of moments or “epiphanies” perceived to have greatly impacted the phenomena of focus in this study (Denzin, 1989). When epiphanies of the development process were identified by studying project artifacts, the lead author would engage in a reflective writing process, detailing recalled challenges of realizing design principles and chronicling how disparate and non-intuitive approaches were required to create the initial prototype. These reflective pieces were then consulted for sense- and meaning-making relative to the transformative moments of our design process, ultimately leading to a holistic representation of MUVE design for individuals with ASD. This gestalt is characterized here as transitive, ill-defined, and complex.
The Case Narrative

The assumption of veridicality suggested that we focus on creating realistic representations of the terrain, buildings, and building interiors that participants would experience when training to use the university shuttle. This also suggested that authenticity was needed in terms of the actual task of using the shuttle. At the outset of the project, we had questions concerning how we could bring together all of these pieces to create a learning environment that could provide sufficient realism to fully instantiate a diverse array of design guidelines.

A realistic terrain was central to the design because the terrain acts as an underlying unifying element upon which the virtual world is based. This extends not only to the space in which objects and avatars act and interact, but also the space in which meaningful activities occur. The assumption of veridicality suggested a need for a terrain that would simulate the experience of an activity performed on campus. While a simplistic, flat terrain certainly would have been simpler by orders of magnitude, it would substantially diminish sensations of reality and potentially distort a user's sense of presence or “being there.” Campus buildings would be off-scale and incorrectly positioned. For example, the campus is hilly and many buildings have multiple entrances on different floors of the buildings. Entering from one side might bring you to the first floor while entering from another side might bring you to the fourth floor. Creation of a terrain that accurately represents the contours of the earth is a challenge. This challenge was outside of our sphere of expertise, requiring that we seek out interdisciplinary knowledge for a solution. How does one model real world terrain in a virtual world? Could geographic information system data (GIS) be employed? What about other topographical elements, such as building placement and roads? How are all of these elements combined? And, ultimately, how could these combined elements be imported into a virtual reality simulation?

Atop the terrain are the campus buildings themselves. We reasoned that buildings that were accurate representations of their real-world counterparts would help promote the assumption of veridicality. However, buildings have complex architecture, and creating accurate 3D models of buildings is incredibly tedious and requires substantial expertise. Hence, we reasoned that architectural accuracy was perhaps less important than photographic realism. Hence, we reasoned that building models did not need necessarily to be entirely true to their real-world geometry. Instead, to create a sense of photographic realism we turned to a variety of interdisciplinary approaches to capture high resolution photographs that could be used as textures for our models.

For the interior designs of our MUVE, however, we took an opposite approach to that which we used for buildings. Instead of focusing on photographic realism, we employed the actual architectural plans of the buildings. Based on the interior elevations and floor plans, we created highly realistic models of the Impact Innovation office space. To increase the fidelity of this model we also went down to the office space and took photographs so that we could align the textures to the real world. We also consulted our pictures to include additional 3D models to the space such as interior furnishings, rugs, computers, and more. This space provided users with a highly authentic-looking space to interact with an online guide and others. In the real world, Impact participants have their own cubicles and are exposed to a variety of activities in this
office space. In the virtual world, this space provided users a connection to the real-world and to their everyday lives.

Central to connecting the above elements to one another was the public transportation training that participants needed to engage in. We developed the virtual version of this task by carefully analyzing exactly how participants performed this task in the real world. An interdisciplinary process was conducted with the help of special education specialists and an applied behavioral analyst to develop a scripted set of routines and behaviors that exactly mirrored what Impact Innovations participants would actually undertake in the real world. A variety of computer programming and game design skills also were required to bring these pieces together.

In the next section, we will provide a case narrative that outlines the process behind bringing together these four elements to create Virtuoso. Table 1, as seen below, outlines the interdisciplinary processes involved in realizing this design principle across the four design problems that we identified while creating this MUVE. The purpose of this table is to outline these complexities and to highlight that an interdisciplinary approach is a requirement.

Table 1. Interdisciplinary Processes Used to Create Virtuoso.

<table>
<thead>
<tr>
<th>Creating the Terrain</th>
<th>Challenge</th>
<th>Interdisciplinary Requirements</th>
<th>Specific examples</th>
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</thead>
<tbody>
<tr>
<td>Affordance</td>
<td>Challenge</td>
<td>Interdisciplinary Requirements</td>
<td>Specific examples</td>
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| Promotes a sense of presence by emulating the lived experiences of actually walking on campus | Generating a geographically realistic contoured mesh with accurate representations of topography | - Geography  
- 3D Design  
- Game Design  
- Graphical Design | - Image Editing  
- 3D Editing  
- GIScience |

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<tr>
<th>Creating Campus Models</th>
<th>Challenge</th>
<th>Interdisciplinary Requirements</th>
<th>Specific examples</th>
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<tr>
<td>Affordance</td>
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<td>Specific examples</td>
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| Promotes a sense of presence by emulating the in situ environment for training. Helps to promote the | Modeling a campus model that was photo-realistic | - Piloting  
- Photography  
- Geography  
- 3D Design  
- 3D Editing | - Photogrammetry  
- Taking photographs  
- Drone Flying  
- 3D Editing  
- GIS Extraction |
assumption of veridicality

Creating Interior Model

<table>
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<tr>
<th>Affordance</th>
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<th>Interdisciplinary Requirements</th>
<th>Specific examples</th>
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| Provides connection to the real-world through a space that participants would be familiar with. | Creating a realistic representation of an interior design. | • Architecture  
• 3D Design  
• Photography | • Converting blueprints into a 3D Model  
• Taking photographs of space |

Creating the Virtual Task

<table>
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<tr>
<th>Affordance</th>
<th>Challenge</th>
<th>Interdisciplinary Requirements</th>
<th>Specific examples</th>
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| Provide a realistic and accurate way of practicing skills to transfer from virtual platform to the real world. | Creating a one-to-one representation of behaviors that both human avatars and in-world assets such as a bus would naturally undergo in the real world. | • Game Design  
• Applied Behavioral Analysis  
• Programming  
• 3D Design  
• Videography  
• Instructional Design  
• Computational Thinking | • System of Least Prompts  
• PHP Programming  
• Javascript Programming  
• 3D Editing  
• Game Design Techniques  
• Shot Ride-along footage  
• Created a task analysis |

Developing a Realistic Terrain

Figure 1, as seen below, was an early representation of how we set out to create our model. The terrain, including slopes and scaling were obtained by extracting geographic information system (GIS) data from Google Earth. After extracting this GIS data, we were able to convert the data into a 3D mesh. In this early version of Virtuoso, we placed a screenshot of a map from Google Maps onto that geometric mesh to create a preliminary terrain of the
Next, we needed to texturize the terrain to include photorealistic representations of the roads, pathways, landscape, and topography. To accomplish this task we had to again iterate through many versions that required varying skills and expertise. On an initial trial we opened the GIS mesh in the Blender (http://blender.org) 3D modeling program so that we could manipulate the millions of polygons that made up the terrain. With the outline of the map placed over the terrain we were able to garner rough approximations of where concrete pathways existed and where patches of grass were. Through a process that encompassed several days, one studio member went through and individually selected the edges of each polygon that would represent concrete pathways. He then applied a texture that closely resembled the concrete used on campus. This process was repeated for the grassy portions of the terrain. Photographs of the roads and topography were taken by a lab member to allow for the selection of a texture that would best match the real world. While this process did allow Virtuoso to iterate closer to a photorealistic representation of campus, the resulting product had a litany of issues. Manipulating massive GIS meshes created problems with collisions, which resulted in “holes.” This led to assets and avatars falling through the base of the world. Repeating textures were also too uniform and did not account for variations in coloring, texturing, and consistency across the terrain.

In the next iteration we again returned to the GIS terrain that we extracted from Google Earth. Now knowing that editing the mesh could result in unforeseen errors, we ultimately decided to leave the geometry alone and to place the topography on top of the 3D object. In this
prototype we took a large high resolution image of the university’s from Google Earth. This allowed us to select the region’s topography in an uninterrupted view. After capturing a high resolution image of this scene we were able to place it over the terrain like we had done with the Google Map image before, which resulted in a terrain that included the university’s natural topography while maintaining an outline of the buildings to help with proper positioning. Figure 3 shows a version of this model in our High Fidelity prototype before any of the buildings had been created or placed.

![Fig. 3. Screenshot of the campus terrain with GIS data image stills mapped onto a 3D mesh.](image)

**Developing Realistic Buildings**

After we had finalized a version of our terrain that was sufficiently realistic, we set out to create 3D models of every single building on campus. This process took approximately 1.5 years to complete and went through many iterations until we reached a level of photographic fidelity that we deemed to be sufficient. One design studio member had some background creating 3D assets, having worked on a virtual reality project in the past. This background allowed him to create assets made up of basic 3D models and shapes. To create the campus buildings we decided that we would create approximations of the structures and then map images onto them to provide a degree of photorealism. To test this process we set out to create a fountain that existed on campus. Two studio members went onto campus and took photos of the fountain from varying angles and perspectives. These images, as seen in Figure 4, would act as the textures of the model that was made. However, scaling this process was ineffective as lighting issues greatly impacted our ability to obtain high quality photos while on campus. In addition, an inability to reach high angles would prevent us from being able to fully capture stills from most of the buildings on campus.
To address these issues we began testing a process called photogrammetry. Photogrammetry is the process of obtaining information about objects and the environment through recording, measuring, and analyzing photographic images and patterns. Knowing that a model could be made by capturing images of a structure, we decided to test the procedure on a large scale basis. The idea was to equip a DJI Phantom Drone with a video camera that would continuously shoot footage as we flew it around a building from various heights, angles, and perspectives. We would then use software to convert the video into frame by frame screenshots that could be used to run an analysis on and thereby create a usable and highly realistic 3D model. Unfortunately, this idea proved to be flawed, as we discovered a variety of technical and safety regulatory barriers. Capturing the amount of footage that would be required to convert the photographic stills into a 3D mesh required prolonged time in the air from many vantage points that our team simply did not have the piloting abilities to perform.

Though we were unable to use drones to capture the images needed to create our 3D mesh, we were still interested in using photogrammetry to get the models that we needed. Instead of capturing images by flying around the campus buildings, we decided to use the same process but in Google Earth. This idea allowed us to “fly” in through different perspectives and to capture images of the buildings on campus. We were able to use the built in tools of Google Earth to zoom in and rotate the models around the x, y, and z axes. We then took individual screenshots within the tool that we imported into a photogrammetry software called Adobe ReCap. Figure 5 demonstrates what this model looked like after we exported it from Adobe ReMake and brought it into High Fidelity.
While this process certainly provided us with model that was more realistic and lively than anything we had accomplished to this point, it was not without its flaws. As seen in Figure 5, there were multiple distortions that resulted from the process. Textures and objects would appeared to be melting together and led to a grotesque, even nightmarish appearance. Knowing that individuals with ASD oftentimes have problems with sensory processing, we were concerned that this model could result in adverse outcomes. This finding did however give us insight into how we could combine multiple processes from our design iterations to create a model of our campus that could maintain their shapes while still having textures with a resolution capable of providing photographic fidelity. The next step of our process involved a return to the campus terrain that we had created prior. We took the high resolution image of the campus map and placed it onto a flat plane which allowed us to view the outlines of the campus buildings. We then opened the map in Adobe Illustrator, a vector image editor, and used the Pen tool to trace the outlines of the different campus buildings. After doing so, we exported the image as a SVG and imported it into Blender. This software has a tool called a Curve Bevel which allowed us to convert the 2D tracings into an extruded 3D rendering of the buildings. Now that we had a model that was scaled and positioned onto the terrain, we had to find a way to provide and map textures onto the faces of each campus building. Knowing that we could not take photos of the individual buildings we once again returned to the photogrammetry process we had tested in Google Earth for creating a mesh. However, instead of using it to create the entire mesh with textures, it was used only for ripping textures that we could place onto the planes of the building faces. Figure 6 shows the final campus model that we used which was a result of a multi-year endeavor that required the use of expertise across many disciplines to create.
Developing Realistic Interiors

After we had finished our campus exterior, the next step of our intervention design required that we re-create an office from the Impact Innovations suite that is located in the Teacher’s College on campus. Taking lessons from our photogrammetry experiments, we decided to skip these procedures in this process and to make the model through other means. Seeing the results that we got from extruding the map outlines we thought we could do something similar through architectural blueprints. We reached out to the building planner for the School of Education and were able to obtain the blueprints from the recent reconstruction of this building and office suite. We then imported it into architecture modeling software called Archilogic which allowed us to create a fully interactive 3D model of this space. We were then able to go down into the actual office and take photos that could be used to create textures for the walls, flooring, and decor. Archilogic also allowed us to bring in furniture, electronics, and other furnishings to populate our office space and make it better simulate its real-world counterpart.
Developing Realistic Scenarios

Early into the development of Virtuoso, we completed a detailed task analysis to determine the structure and nature of the activities that should take place within the MUVE. This task analysis required assistance from an Impact Innovations staff member who was familiar with the day-to-day scheduling of the day program. This staff member was able to provide us with a step-by-step series of behaviors that was necessary to complete the task of getting onto a shuttle bus by an Impact Innovations associate. We then went with the staff member and a program associate and recorded the two of them completing these tasks to expand upon and improve the task analysis that we had created. Next, we worked with an applied behavior analyst to modify the tasks to include opportunities for interaction and behavioral prompts. Figure 8 illustrates a portion of our task analysis that includes an ABA technique called the System of Least Prompts (Doyle, Wolery, Ault, & Gast, 1988).
Fig. 8. A portion of a Virtuoso task analysis with ABA strategies incorporated.

Embodying realistic activity within the learning process required that we simulate real world tasks in the virtual environment with a high degree of fidelity. Therefore, after we had mapped out the behaviors, activities, and structure of the intervention, we needed to develop a solution to bring them to life into our 3D environment. Part of this process included the creating a shuttle bus that could arrive on a set schedule when participants had completed the required steps to get to the shuttle stop and check their app to see where the bus was along the route.

High Fidelity is a Beta VR toolkit which meant that their documentation and API was constantly evolving and oftentimes absent. This limitation prevented us from being able to access into the system to create a solution that could readily be implemented. In addition, due to the relative immaturity of the software, there were no existing plugins that could provide us guidance on even animating an object in our project. We instead looked towards the gaming industry to develop a solution to animate a bus along a route. In the popular video game *Fallout 3* there was a rideable train that was actually just a non-playable character wearing a hat that looked like a giant train. To borrow this idea for our project, we created a model of a university shuttle bus that we then equipped onto an avatar as a hat attachment. High Fidelity also had a recorder tool which allowed us to record avatar movements that could be activated and played on a loop when a player loaded into the world. This process allowed us to create a functional shuttle route, but not without its limitations.

These recorded loops did not maintain any of their asset’s physics or collisions which meant that playable avatars and other in-world items could pass through them. With road safety and socially appropriate behaviors related to catching the bus being a pivotal point of our intervention, it was not suitable for a player to be able to walk into and through a bus that was driving along a route. We had to come up with another solution to emulate a bus along its route.
Solving this problem would ultimately require the development of multiple scripts that could handle different components of the shuttle’s movement and timing. We were able to create a script that was based off of a 3D elevator that moved from point A to point B. This PHP script assigned the shuttle model to an object that was then translated across 3D coordinates. We were then able to assign a set speed for this animation with a variable in the script. So we took the shuttle model and hid it out of sight from where participants would be at the time that the script would initialize. To control the timing of the shuttle we hid an invisible cube into the environment that acted as a trigger to initiate the shuttle’s movement. When a player walked through the cube it would load a Javascript code that controlled the activation of the shuttle’s PHP movement code. During our intervention’s usage, an invisible player would walk into the cube during a sequence that took place in the task analysis. By walking into it at this exact moment, we were able to emulate a bus that would arrive based upon a shuttle’s location within a tracking application and could therefore replicate the real-world in this virtual activity.

Fig. 9. An invisible player in the world would activate the bus script based upon information from the shuttle tracking application that was embedded within the virtual environment.

**Lessons Learned**

As demonstrated through this case narrative, creating a MUVE for individuals with autism it is an interdisciplinary process that requires an interdisciplinary team by its very nature. Problem solving along each dimension required interdisciplinary solutions and it is likely that
others working in this field will have similar issues and will benefit from developing a sensitivity for when seeking interdisciplinary perspectives could be effective. Our analysis of project artifacts have shown that designing a MUVE to embody users within the learning process required a broad application of skills and expertise that spanned across many disciplines.

Creating a MUVE that is capable of promoting skills development and transfer is a lot more complex than just ensuring a degree of photorealism. The experience itself also has to be realistic. Users need to feel embodied within the environment and task itself. Bringing all of these pieces together required years of development by a small design studio to create one version of a singular learning scenario. This revelation in itself illustrates the considerable research to practice gap that still exists in the field. While virtual reality is touted as a valuable technological solution to promote the development and transfer of skills for people with autism (Parsons, 2016), that promise simply has not panned out. Creating a MUVE that is capable of instilling the design considerations from the literature is vastly difficult and multifaceted.

The team behind the development of Virtuoso took the best available evidence from the field in an attempt to realize the promise of VR for this population, but in the process of doing so realized that it takes a massive amount of work to provide an environment that is photographically realistic and authentic in design. The task of creating a single scenario of limited variability required a massive amount of labor, thinking, and problem solving to ultimately create an environment with graphics of Google Earth level quality. For any team to be successful at developing a MUVE they have to decide to use commercial off-the-shelf software or to build it themselves. And knowing that there is nothing on the market that allows you to create a photographically realistic environment, other developers in the field will likely undergo many of the same challenges that we did to create Virtuoso.
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