Virtual Reality and Spatial Cognition

Clinical Benefits and Multi-Perceptual Learning in The Virtual World

By Chad Jordan – May 20th 2017

What is Spatial Cognition?

According to ScienceDirect.com, Spatial cognition is a complex, multifaceted set of processes that are engaged in a large variety of tasks, including, for example, mental rotation, spatial navigation, and spatial working memory. This is the knowledge and internal or cognitive representation of the structure, entities, and relations of space; the internalized reflection and reconstruction of space in thought. The cognitive systems include mental processes whose core components include thinking, imagining, perception, sensation, learning, memory, reasoning, and problem-solving. This process of spatial cognition influences the dynamic relationships between the human psyche and our spatial environments. Our survival and existence are intrinsically related to this relationship between space and people.

VR in Education

Spatial processing skills are an important aspect of cognitive development and many students are retaining more information in education through visual learning. According to Dr. Lynell Burmark, Education Consultant and CEO at educatebetter.org says it has been shown that there are many students who, because of their perceptual differences could use assistance in developing spatial concepts and relationships through experience in multi-perceptual alternative learning environments. She explains that making the most of visual learning allows information and data to transmit messages faster, improves comprehension, and long-term memory skills. These are just a few of the reasons why we should understand the importance of VR in education. Bringing VR tools into the classroom doesn't have to be expensive. Available resources, ranging from low-priced viewers like Google Cardboard to cost-effective equipment that can connect to smartphones, can be acquired without breaking the bank. Resources for teachers include affordable or even free apps, such as 360Cities, which allows students to visit places like Rome and Tokyo. Another app, TimeLooper, allows students to visit locations through a historical lens, such as London in medieval times or World War II. Platforms like Immersive VR Education and Nearpod allow teachers to develop lesson plans with VR and AR technology. In the 21st century, information and knowledge have only become more readily available to everyone. Even though these aspects of learning have become more easily available to society, the current approach to education has two significant problems:

- **<u>Knowledge is based on a traditional format — retaining information.</u>** Teaching methods are focused on providing facts about information; however, having access to and consuming a lot of information isn't learning. Being informed isn't the same as being educated.

- **<u>Many people have difficulties comprehending information.</u>** Too much information received in a short period of time can easily overwhelm students. As a result, they become overwhelmed, disengaged, and demotivated to keep retaining information.

So how can Virtual Reality benefit education? VR can enhance student learning and engagement which can provide higher retention in memory. A virtual experience can transform the way educational content is delivered to students; it works on the premise of creating a virtual world — real or imagined — and allows users not only to see it but also interact with it. Being immersed in what you're learning motivates you to jump deeper, and fully understand it. It'll require less cognitive load to process the information, while also improving cognitive processing in the frontal lobe of the brain. Children can learn more about the inner workings of human anatomy from a younger age, and through an immersive, interactive experience.

Here are a few components that make implementing virtual reality a significant advantage in education:

1) **<u>A greater sense of environmental learning</u> -** When children read about environmental locations or topics, they generally want to experience it. With VR, students aren't restricted to word descriptions or book illustrations; they can explore the topic and see how things are put together by directly interacting with it. The magic of VR is that it brings different places throughout the world right into the classroom. These new perspectives can result in fostering empathy and cultural competence because they take students outside of their normal daily experiences. The use of VR helps students understand people's unique situations across the world.

2) **<u>Learning through immersive experiences</u> -** We all know people learn best by doing. If you research modern education, you'll see how much learning actually happens by doing, especially in (STEM) ***Science Technology Engineering Mathematics*** education. Although, many students are focused on reading instructions rather than using them in practice. VR in education provides an experienced anchor to the instruction. With VR education, learners are inspired to discover for themselves through experience. Students have an opportunity to learn by doing rather than passively reading.

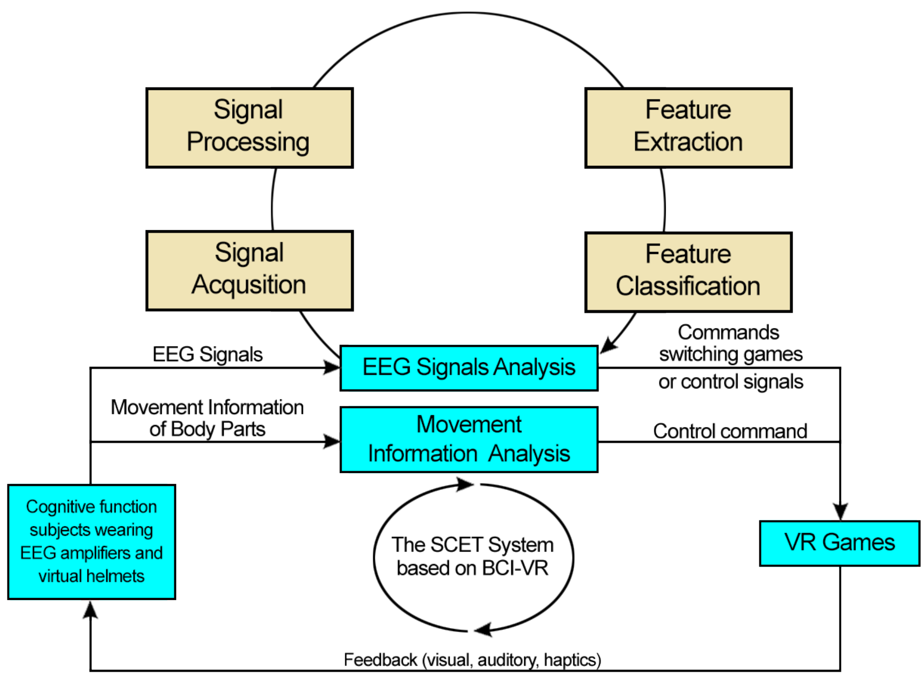
3) **<u>Virtual fields trips</u> -** VR technology can be used to engage students in subjects related to geography, history, or literature by offering a deeply immersive senses of place and time. Simply imagine geography lessons where you can visit any place on the globe — this type of experience is much more enriching than just reading about it. Google Expeditions is one good example of an app designed to provide such an experience. Expedition is a library of field trips available for regular smartphone users. Each trip is comprised of VR panoramas, and trips vary from the Great Wall of China to the Moon,

or even Mars. People all over the world can visit places that are virtually impossible to visit in person.

4) **Distance learning** - VR allows us to bridge the gap between educators and learners. With VR, distance learning tools can put educators and students together in the same room with digital representations of themselves — teachers can teleport into the VR world and guide students through their experiences.

Research Analysis of SCET with BCI-VR

Spatial cognitive evaluation and training *(SCET)* is a rapidly growing research field in cognitive study. SCET is also greatly significant in the diagnosis and rehabilitation of mild cognitive impairment *(MCI)*, mainly because patients with MCI show symptoms of spatial cognitive impairment at an early stage. For SCET, real-time and accurate quantification is the ultimate goal in evaluation; it is expected to have a strong sense of participation for the subjects in training, and the training content is closely related to their daily life. VR and brain-computer interface *(BCI)* are popular technologies in SCET. Training with VR meets the experience and social needs of subjects and can be used as the main way of spatial cognitive training *(SCT)*. According to Walter Bischof and Pierre Boulanger from the University of Alberta, there are presently several studies that combine BCI and VR to apply their respective advantages in the field of SCET. For spatial navigation in BCI, theta oscillation of electroencephalogram *(EEG)* signals are related to the encoding and retrieval of spatial information when performing VR maze navigation tasks. This unequivocally compared the differences in EEG signals from male and female adults in the theta frequency band with VR spatial navigation tasks. For the spatial memory combined BCI with VR to observe differences in EEG activity during the coding and retrieval stages of spatial memory tasks. For another spatial task, used VR day-out task to evaluate its predictive value of MCI. This SCET research verifies the rationality of the combination of BCI and VR. The following diagram displays the description and system process of the SCET with BCI-VR. Here we see the interconnected relationships between the cognitive function to EEG signals and the intrinsic data that is processed, extracted, and analyzed when movements are recorded during control commands.



Clinical Benefits of VR

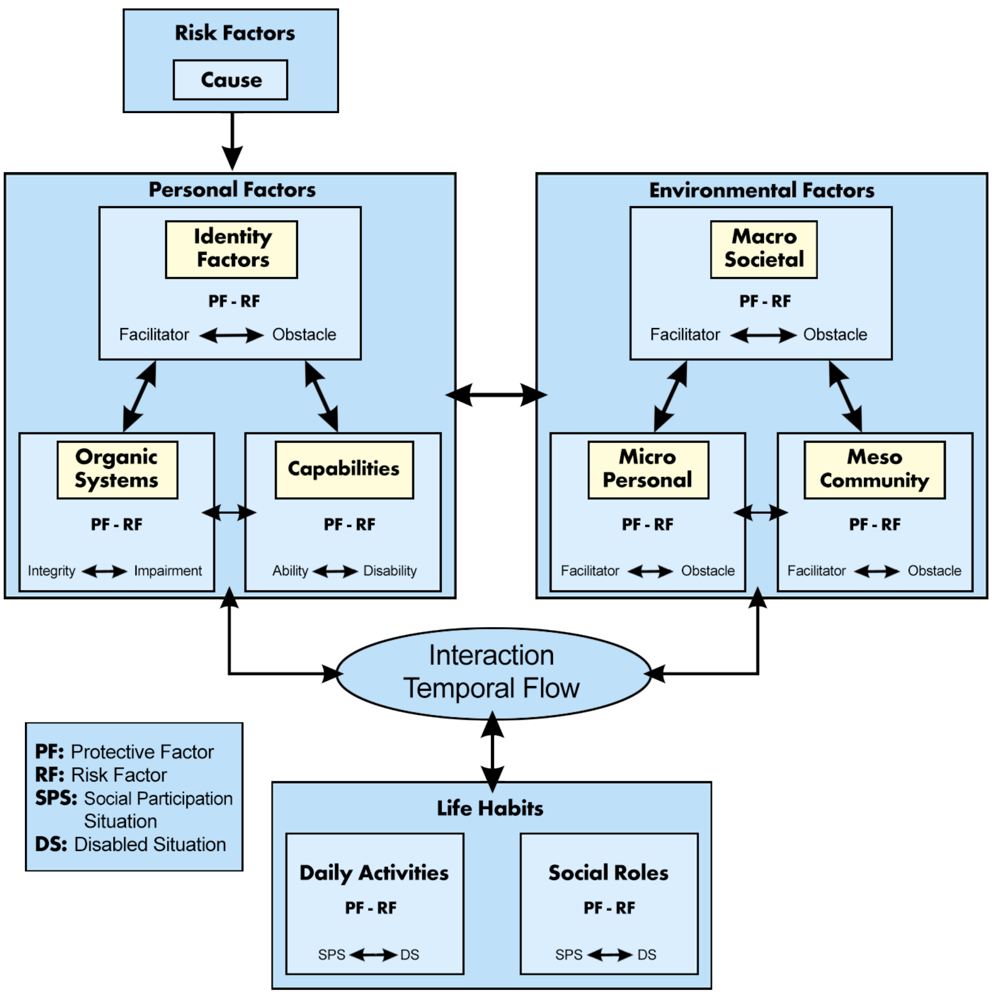
The above data regarding motor functions and neural responsiveness to SCET research is absolutely vital to clinical studies such as patients that suffer from Alzheimer's, dementia, and other mental health disorders, including PTSD and body dysmorphia.

Organizations such as Limbix, LibraVR, MindMaze, and Immersive Rehab are just a few examples of people that are making use of VR in neurological therapy in settings from hospitals to individuals at home. According to alz.org on some varied levels, the physiological change of cognitive decline occurs during the aging process that occasionally evolves into a subtle condition known as **mild cognitive impairment *(MCI)***. Even though this is not traditionally diagnosed like dementia, MCI is still a condition that can result in detrimental dysfunctional behavior on the elderly's cognitive functions. However, unlike dementia, MCI could technically revert back to a normal condition or stabilize over time. The decline in cognitive functioning negatively affects elderlies' independent living and their ability to safely and autonomously carry out **instrumental activities of daily life *(IADLs)***, an assessment instrument that measures an individual's ability to perform daily activities such as grocery shopping, managing medications and/or money, and housework. When it comes to Alzheimer's/dementia patients, they need brain stimulation to help delay the decline of their thinking skills. VR simulations can help exercise parts of the brain that become deteriorated on account of one or more strokes. One example of this in practice is the Sea Hero Quest VR app from Alzheimer's Research UK. The app assists with spatial navigation and completing small tasks that allow the user/participant to engage in interactive nautical environments, therefore stimulating brain activity. This app was just released last year and has already reached game platform websites like gamesforchange, hyperxgaming, citizensciencegames, and making an impactful presence on social media with Twitter and YouTube.

One of the first symptoms of dementia is a loss of navigational skills, Sea Hero Quest provides enough data to help create the world's first benchmark for human spatial navigation. The intuitive nature of Sea Hero Quest VR allows us to track even more subtle and detailed reactions such as eye movements, as well as replicate highly credible lab-based experiments not possible in a mobile setting. The purpose of VR apps is to exercise motor functions in the brain to assist in the cognitive thought process. According to the *Disability Creation Process Model* mentioned in the Canadian Journal of Occupational Therapy *(CAOT)*, the negative impacts on life participation can be created when functional limitations *(e.g. communication problems)* interact with environmental factors *(e.g. negative attitudes)* that are non-facilitating. Three interacting domains are used to describe the lived experience of individuals with functional limitations in creating successful engagement in life activities.

1) **Personal Factors –** pertaining to cognitive sensory transmissions from organic systems and capabilities, combining all components of the human body that interrelates with the individuals' potential to perform mental or physical tasks. Additionally, there are variables such as age, sex, and socio-cultural identity, as well as the consequences on processes such as perception, memory, and language.

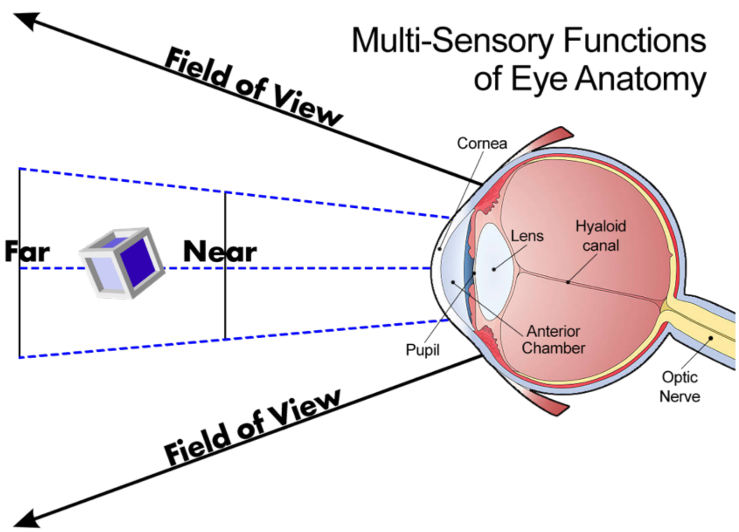
2) **Environmental Factors –** encompasses the resources *(facilitators or obstacles)* within the individuals' living dimensions. In dementia, for instance, this might include the physical design of long-term care facilities, the attitude of the general public, or access to health coverage. These factors influence the living experiences as they can make life easier or harder as the patient transitions through the journey of resolving dementia.



3) **Life Habits –** refers to the result of the interaction from the first two domains as they impact the living experiences valued by the individuals and their respective socio-cultural context. This domain encompasses important life areas such as work, interpersonal relationships, community involvement, etc.

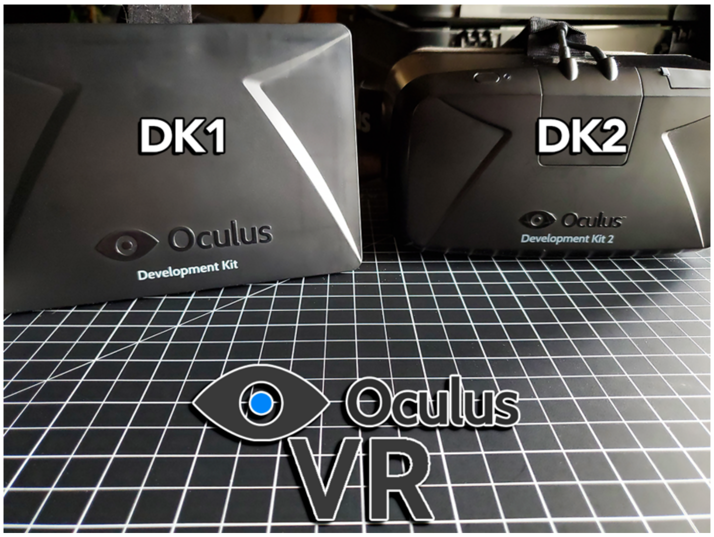
Fundamentally, the Disability Creation Process Model offers a framework in which to understand the relationships among all the domains and help identify areas that may improve the living experience through the modification of either or all of the domains.

When considering the timeline of dementia, the patient has about 3 years from when MCI is first diagnosed before dementia settles in. When we consider that MCI is characterized by both cognitive-behavioral and neural impairments, a successful rehabilitation process should address both of them and could benefit from the integration of technological advancements. A plausible technology could be virtual reality due to its psychological and technological features: VR scenarios simulate daily life situations in which the user can feel immersed and interact with an environment updated in real-time, while also receiving dynamic multi-sensory feedback with visuo-spatial processing. Dementia patients need to practice where objects are in space through spatial navigation and thus stimulating visuo-spatial processing. This processing of **Field of View** *(FoV)* is performed much like a camera in 3D space. I created a similar diagram in my past guide to Interactive Computer Graphics. The human eye is like a 250-megapixel camera, picking up extreme detail of objects around us, but this is only done within our FoV. These images that our eyes capture is sent to our brain through a series of multi-sensory functions passing through the anatomy of our system. When people suffer from various Alzheimer's diseases, these initial functions of the eye may work, but these components become impaired by the deterioration of memory and motor skills of the mind which in turn impacts other areas of the body. This is all the more reason why we focus our attention early on stimulating these areas for patients who are in the early stages of dementia. MCI is a transitional subclinical entity creating a fine line between normal and pathological aging. Thus, early interventions are essential to preserving cognitive functioning and, as far as possible, to decelerating its evolution toward dementia. MCI may benefit from an efficacious intervention considering that the brain might still be able to compensate for its deficiencies and to support the acquisition and retention of the impaired cognitive functions. With the progression of pathological conditions and the spreading of lesions instead, the brain might no longer be able to compensate. Thus, a prompt rehabilitation is required in delaying the progression of dementia. Considering that both VR-based training and neuromodulation capitalize on neuroplasticity, they can enhance the therapeutic mechanisms in a healing way.



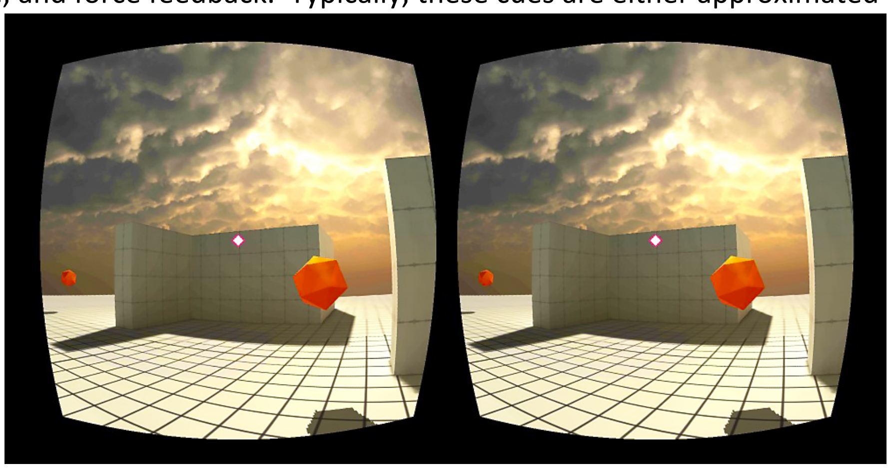
VR as An Assessment Tool

Whether in the field of Human-Computer Interaction *(HCI)* or working in another area of the medical field for dementia patients, a technology designed for immersive, virtual environments gives researchers the opportunity to study how persons with dementia interact with their environment. This is why throughout my research in HCI and clinical therapy for Alzheimer's diseases, I have experimented with and built some of my own VR applications to use for research. To accomplish this endeavor, I turn to my Oculus VR Dev Kits. The first development kit *(DK1)* headset was really the beginning of the journey for consumer VR. The first few dev kits were prototypes designed for developers that wanted to create VR apps. For those who are unaware, the first development VR kit *(DK1)* for the Oculus headset was released in March of 2013 after a successful Kickstarter campaign surpassing the 250,000 goal and reaching 2.4 million from online backers. At this point, Oculus was in business, and making its first VR headsets for the consumer. The Dev Kit 2 *(DK2)* was later released in July of 2014 and with considerable upgrades like 1080p resolution, significant improvement of eye latency, and the first VR headset to use optical camera-based motion tracking, I pre-ordered the DK2 so I could experiment in the next evolution of VR technology. While anyone could pre-order these dev kits, they were merely the testing grounds for the official consumer version *(CV1)* that would later release in March of 2016. I have kept up with development using my dev kits, but I have yet to purchase the consumer model Oculus CV1 headset. It's only been out a little over a year but with the further online discussion regarding the next generation of Oculus headsets, I'm intrigued to see more feedback before considering another purchase. As of now, VR is expanding into other organizations that are also wanting to harness the technological reins of this growing field.

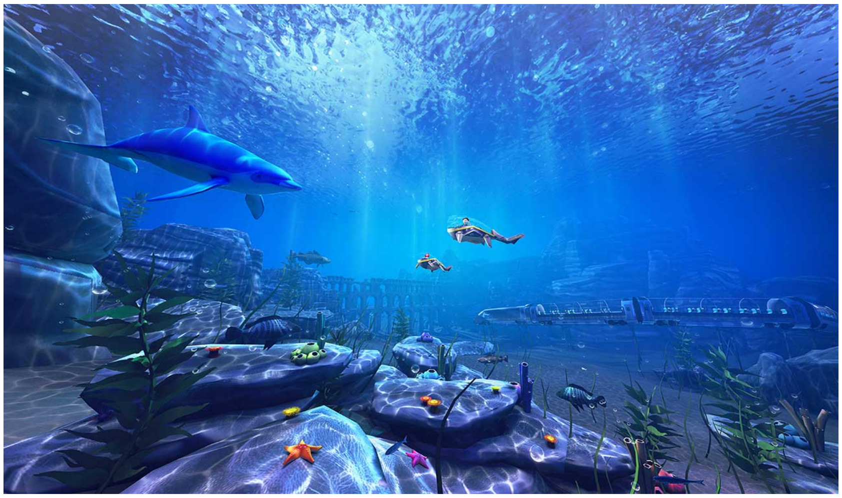


Considering that Augmented Reality (AR) and Virtual Reality (VR) have pioneered their way into the tech industry, we as a society see a significant technological shift toward the user. This

emphasis gives way to new innovative techniques for how we can assess behavioral science using AR and VR technologies. I have already performed my own case assessments using my VR headsets on how the user responds to visual and auditory spatial environments. While every scenario in HCI cases involve feedback through observing the user interaction with the product being tested, the immersive experience of VR influences a more emotional reaction. This stimulation of neural-network responses provides additional feedback beyond the case forms and observation of the user/participant, but also vital mental responses for patients that are in need of navigation instructions for spatial environments. Throughout this research, we are not only concerned about virtual environments *(VE)* but the interaction of objects within the virtual environments. Training and simulation VR systems, which make up a substantial number of deployed systems, aim to recreate real-world experiences. The accuracy in which the virtual experience recreates the actual experience can be extremely important, such as in medical and military simulations. The fundamental problem is that most things are not real in a VE. Of course, the other end of the spectrum – having all real objects – removes any advantages of using a VE such as quick prototyping, or training and simulation for expensive or dangerous tasks. Having everything virtual removes many of the important cues that we use to perform tasks, such as motion constraints, tactile response, and force feedback. Typically, these cues are either approximated or not provided at all. Depending on the task, this could reduce the effectiveness of a VE. Even interactions within abstract spatial environments prove to be useful for patients or participants that are stimulating cognitive functions. The participant interacts with objects in the VE, simulations, and system objects. The methods to interact will vary on the task, participants, and equipment *(hardware and software)* configuration. For example, the interactions to locate 3D objects in orientation and mobility training for the visually impaired are different from those in a surgery planning simulation. Variables to consider include accuracy, lag, intuitiveness, fidelity to the actual task, and feedback. Applying 3D transformations and signaling system commands are the most common virtual object interactions. VR issues include the lack of a registered physical object with the virtual object and the limited ways of getting inputs to the system. This poses difficulties because we rely on a combination of cues including visual, haptic, and audio, to

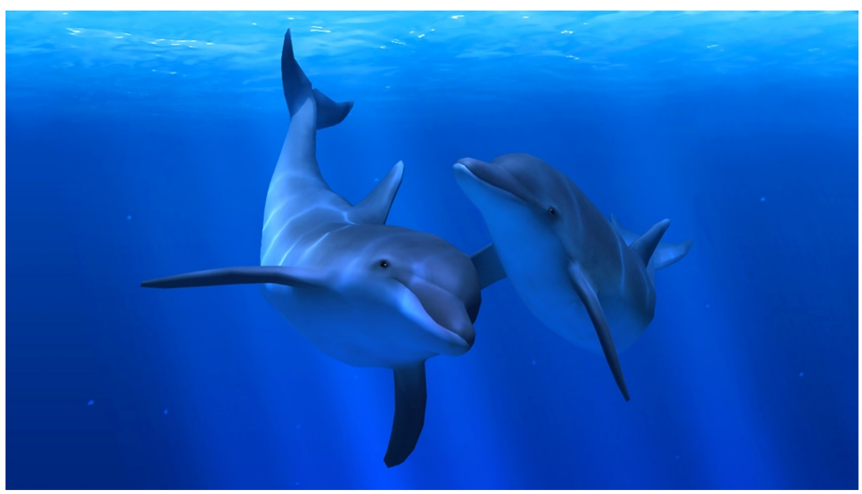


perform many cognitive tasks. The lack of haptic cues from a VE with purely virtual objects could hinder performance. Given that most objects are virtual, can a system without motion constraints, correct affordance, or haptic feedback still remain effective? Is it even possible? These are some of the basic research questions that are being explored, and it is the system designers' job to provide interaction methodologies that do not impede system effectiveness.



VR systems use simulations for a variety of tasks, from calculating physics (i.e. collision detection and response) to lighting to approximate real-world phenomena. Most VR systems require participant interaction to control simulation objects and the simulation itself. For example, in an ocean simulation, the participant can either draw away or entice marine mammals in various locations by providing input such as pressing buttons for swimming closer toward crustaceans and mammals.

Many simulations focus on recreating realistic experiences for the participant. Implementing natural movement and interactions improves realism. However, this adds to the difficulty of high-quality VR interaction. We can engineer specific objects, for example, a prop camera for underwater photography with the shutter-release sensor connected to the computer, but that increases cost and reduced generality (the prop has limited uses in other applications). On the other end of the spectrum, using a generic interaction device, such as a tracked joystick, might prove too different than the actual task to provide any benefit.



These types of real-life experiences are readily available to some, but for those who are not in a place where they can easily experience the coral reef, or swim up close with dolphins, these immersive and interactive VR experiences can captivate the imagination of millions.

Final Consensus

A lot of people most likely associate VR with the entertainment industry in gaming and they wouldn't be wrong in doing so. Hopefully, this article examines and provides a detailed analysis of other vital areas of research in clinical psychology and therapy. While I do stand by the research and data comprised in this article, I can confidently, and personally speak to the technological advantages of visual, interactive learning. On the other side of the spectrum, I was an 80s/90s child so all I had were my textbooks and pencils. The only computer in my classrooms was an original ('86) Macintosh Plus computer in the back of the room that students took turns using. The idea of individual students having their own computers at their desks was nonexistent. An important art form slowly fades away when we move past the days of #2 pencils and cursive writing in textbooks, but the advancements of the technological age are overwhelmingly inevitable. I also believe the ability to have free range at the open plains of the information age also provides a danger to children whose minds are still in development. This concern obviously goes well outside the realm of VR, but VR also makes it easy for underage kids to experience adult content which can be all the more dangerous to developing minds. We know this has been the case with general technology for a long time, and any device that can tap into that network comes with its own risks. Ergo, just like any other technology, it's up to us to use VR for the great things that it can do. With this in mind, we consider how well children continue to adapt to technology in education. Children today are exposed to a much wider spectrum of diverse technology and learning from an earlier age, which will make them more comfortable to use it longer term. From a technological standpoint, I support the changes that have taken place in education and the, *"learning through doing"* mentality fits the newer generation for educating children.

For clinical advancements in Alzheimer's therapy, the future of VR can only become more immersive creating newer changes to how we evaluate therapy for healing the mind and thus restoring cognitive skills. Since Sea Hero Quest is still in its early release, it will be interesting to see what data comes from increasing participants using the app. VR does more than just healing people who suffer from dementia. The technology can also be used for helping those who suffer from depression and other fears such as **acrophobia** *(fear of heights)*, **nyctophobia** *(fear of the dark)*, **aerophobia** *(fear of flying)*, and many other phobias. Per my own case studies, and that of larger organizations VR has proven data to help heal and reverse deteriorating mental illnesses.