A Virtual Reality Scenario for All Seasons: *The Virtual Classroom*

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ABSTRACT

Treatment and rehabilitation of the cognitive, psychological, and motor sequelae of central nervous system dysfunction often relies on assessment instruments to inform diagnosis and to track changes in clinical status. Typically, these assessments employ paper-and-pencil psychometrics, hands-on analog/computer tests, and rating of behavior within the context of real-world functional environments. Virtual reality offers the option to produce and distribute identical "standard" simulation environments in which performance can be measured and rehabilitated. Within such digital scenarios, normative data can be accumulated for performance comparisons needed for assessment/diagnosis and for treatment/rehabilitation purposes. In this manner, reusable archetypic virtual environments constructed for one purpose can also be applied for applications addressing other clinical targets. This article will provide a review of such a retooling approach using a virtual classroom simulation that was originally developed as a controlled stimulus environment in which attention processes could be systematically assessed in children with attention-deficit/hyperactivity disorder. This system is now being applied to other clinical targets including the development of tests

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that address other cognitive functions, eye movement under distraction conditions, social anxiety disorder, and the creation of an earthquake safety training application for children with developmental and learning disabilities.

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INTRODUCTION

Virtual reality (VR) has now emerged as a promising tool in many domains of therapy and rehabilitation.[1-3] The unique match between VR technology assets and the needs of various clinical application areas has been recognized by a number of authors[2,4-9] and an encouraging body of research has emerged.[1,7] Continuing advances in VR technology along with concomitant system cost reductions have supported the development of more usable, useful, and accessible VR systems that can uniquely target a wide range of physical, psychological, and cognitive clinical targets and research questions. What makes VR application development in the assessment, therapy, and rehabilitation sciences so distinctively important is that it represents more than a simple linear extension of existing computer technology for human use. VR offers the potential to create systematic human testing, training, and treatment environments that allow for the precise control of complex, immersive, dynamic three-dimensional (3-D) stimulus presentations, within which sophisticated interaction, behavioral tracking and performance recording is possible. Much like an aircraft simulator serves to test and train piloting ability, virtual environments (VEs) can be developed to present simulations that can assess, treat, and rehabilitate human functional performance under a range of stimulus conditions that are not easily deliverable and controllable in the "real-world." When combining these assets within the context of functionally relevant, ecologically enhanced VEs, a fundamental advancement could emerge in how human functioning can be addressed in many clinical and research disciplines. This potential was recognized early by VR pioneer, Myron Krueger,[10] in his prophetic statement that, "...Virtual Reality arrives at a moment when computer technology in general is moving from automating the paradigms of the past, to creating new ones for the future."

Treatment and rehabilitation of the cognitive, psychological, and motor sequelae of central nervous system (CNS) dysfunction often relies on assessment devices to inform diagnosis and to track changes in clinical status. Typically, these assessments employ paper-and-pencil psychometrics, hands-on analog tests, computer-delivered continuous performance tests and observation/rating of behavior in real-world functional environments or within the context of physical mock-ups. On one end of the spectrum, traditional neuropsychological approaches commonly use paper and pencil-based psychometric tests and training methodologies for impairment assessment and rehabilitation. Although these approaches provide highly systematic control and delivery of performance challenges, they have also been criticized as limited in the area of ecological validity, that is, the degree of relevance or similarity that a test or training system has relative to the real world, and in its value for predicting or improving daily functioning.[11-13] Adherents of this view challenge the usefulness of constrained paper-and-pencil tests and analog tasks for addressing the complex integrated functioning that is required for successful performance in the real world.

On the other end of the spectrum, a common method applied in the occupational sciences discipline to assess and rehabilitate functional abilities employs behavioral observation and ratings of human performance in the real world or via physical mock-ups of functional environments.[3] Mock-ups of daily living environments (ie, kitchens, bathrooms, etc.) and workspaces (ie, offices, factory settings, etc.) are typically built, within which individuals with motor and/or cognitive impairments are observed while their performance is evaluated. Aside from the economic costs to physically build these environments and to provide human resources to conduct such evaluations, this approach is limited in the systematic control of real-world stimulus challenges and in its capacity to provide detailed performance data capture. Futhermore, many functional environments in everyday life do not easily lend themselves to mock-ups, as is readily apparent in the domain of driving skill assessment and training. In this regard, "behind-the-wheel" driving assessments, considered to be the gold standard in this area, are often conducted in only the safest possible conditions (ie, good weather, low-traffic roadways, etc.), and actually provide a limited "window" into how driving performance would fare under more realistic (and often unpredictable) conditions.

A primary strength that VR offers assessment and rehabilitation is in the creation of simulated

realistic environments in which performance can be tested and trained in systematic fashion. By designing VEs that not only look like the real world but actually incorporate challenges that require functional behaviors, the ecological validity of assessment and rehabilitation methods could be enhanced.

Within a VE, the experimental control required for rigorous scientific analysis and replication can still be maintained within simulated contexts that embody the complex challenges found in naturalistic settings. Thus, on a theoretical level, VR-derived results could have greater predictive validity and clinical relevance for the challenges that patients face in everyday life. On a more pragmatic level, rather than relying on costly physical mock-ups of functional assessment and rehabilitation environments, VR offers the option to produce and distribute identical "standard" simulation environments. Within such digital assessment and rehabilitation scenarios, normative data can be accumulated for performance comparisons needed for assessment/diagnosis and for treatment/rehabilitation purposes.

While the expense to produce a standard VE may be initially high, this financial outlay could be dissipated with cost sharing by professionals adopting the environment. Reusable archetypic VEs constructed for one purpose could also be applied to other clinical targets. This has now been done with a "Virtual Classroom" scenario. While originally developed as a controlled stimulus environment in which attention processes could be systematically assessed in children in children with attention-deficit/hyperactivity disorder (ADHD) in the presence of varying levels of distraction, the system is now finding use for other clinical targets. Such applications that are being developed and tested using the Virtual Classroom include: expansion of the range of attention assessment tests (ie, a Stroop Interference testing system for all ages); translation of the Virtual Classroom to a wide field of view (FOV) display system to study eye tracking under distracting conditions in children with ADHD; development of the Virtual Classroom as a tool for anxiety assessment and graduated exposure therapy for "speaking in front of a class of your peers" in children with social anxiety disorder; an extension to the classroom to include a maze of halls leading out of the school for an earthquake evacuation and safety training application for persons with Down's syndrome and for children with learning disabilities.

This article will briefly describe the development of the VR classroom, along with some of the initial findings on its use with children with ADHD. This will be followed by a discussion of the environment as it is being developed and applied to new clinical targets. With current advances and continued cost reductions in both the hardware and software tools needed to use VR for clinical applications, a case will be made for the idea that significant benefits are looming on the horizon for the further integration of this form of simulation technology in the mental health and rehabilitation sciences.

THE VIRTUAL CLASSROOM PROJECT

Origins and Rationale

The original Virtual Classroom project began in 1999 as part of a basic research application program at the University of Southern California in Los Angeles aimed at developing VR technology applications for the study, assessment, and rehabilitation of cognitive and functional processes]. This work has primarily focused on the development of systems that address the cognitive and functional impairments seen in clinical populations with some form of CNS dysfunction. This work was seen to have the potential to improve our capacity to understand, measure, and treat the impairments typically found in clinical populations with CNS dysfunction as well as advance the scientific study of normal cognitive and functional/behavioral processes.

The Virtual Classroom is a head-mounted display (HMD) VR system for the assessment and possible rehabilitation of attention processes. This scenario has since been evolved from a research application into a more advanced prototype that is currently undergoing initial standardization testing. Our efforts[2] to target this cognitive process were supported by the widespread occurrence and relative significance of attention impairments seen in a variety of clinical conditions across the human lifespan. Most notably, attention difficulties are seen in persons with ADHD, acquired brain injury, and as a feature of various neurodegenerative disorders (ie, Alzheimer's disease, stroke, etc.). VR technology appears to provide specific assets for addressing these impairments that are not available using existing methods. HMDs that serve to occlude the distractions of the outside world are well suited for these types of cognitive assessment applications. Within an

HMD, researchers and clinicians can provide a controlled stimulus environment where attention (and other cognitive) challenges can be presented along with the precise delivery and control of "distracting" auditory and visual stimuli within the VE. This level of experimental control allows for the development of attention assessment/rehabilitation tasks that are more similar to what is found in the real world and when delivered in the context of a relevant functional VE, stand to improve on the ecological validity of measurement and treatment in this area.

Our first project with the Virtual Classroom focused on the assessment of attention in children with ADHD. The heterogeneous features of ADHD, a behavioral disorder marked by inattention, impulsivity, and/or hyperactivity, have made consensus regarding its diagnosis difficult. Furthermore, traditional methods for assessing attention in children with ADHD have been questioned regarding issues of reliability and validity. Popular behavioral checklists have been criticized as biased and not a consistent predictor of ADHD, and correlations between concordant measures of ADHD, such as parent and teacher ratings of hyperactivity, have been repeatedly shown to be modest at best and frequently low or absent.[14,15] Due to the complexity of the disorder and the limitations of traditional assessment techniques, diagnostic information is required from multiple types of ADHD measures and a variety of sources in order for the diagnosis to be given.[14-17] Thus, in the area of ADHD assessment where traditional diagnostic techniques have been plagued by subjectivities and inconsistencies, it was believed that an objective and reliable VR approach might add value over existing approaches and methods.

THE VIRTUAL CLASSROOM SYSTEM

The initial research version of the system was run on a standard Pentium 3 processor with the nVIDIA G2 graphics card. The HMD used in this study was the V8 model from Virtual Research. Tracking[18] of the head, arm and leg used three six-degree of freedom magnetic "Flock of Birds" trackers from Ascension Technology Corporation.[19] In addition to tracking head movement in real time to update the graphics display in the HMD, the tracking system also served to capture body movement metrics from the tracked locations. This provided concurrent data on the hyperactivity component that is a com-

monly observed feature of ADHD. The research version of the Virtual Classroom scenario consisted of a standard rectangular classroom environment containing desks, a female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a playground and street with moving vehicles, and on the opposite wall, a pair of doorways through which activity occurred (Figure 1). Within this scenario, children's attention performance was assessed while a series of common classroom distracters (ie, ambient classroom noise, activity occurring

FIGURE 1.
Scenes from the initial research version of the Virtual Classroom

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outside the window, etc.) were systematically controlled and manipulated within the VE. The child sat at a virtual desk within the Virtual Classroom and on-task attention was measured in terms of reaction time performance and error profiles on a variety of attention challenge tasks that were delivered visually using the blackboard or auditorily via a virtual teacher's voice.

USER-CENTERED DESIGN PILOT TESTING

Prior to any clinical tests, the early application of user-centered design methods is vital for the reasoned development of any VR application.[20,21] User-centered methods generally require the involvement of the targeted user group to provide feedback in the early design and development phase of scenario development. In the Virtual Classroom's user-centered design evaluation phase, 20 non-diagnosed children (6–12 years of age) tried various evolving forms of the system over the first year of development and their performance was observed while trying out a variety of basic selective and alternating attention tasks. All of the research presented in this article from all projects was approved by an institutional review board and written informed consent was obtained from subjects and their legal guardians if children. We also solicited feedback pertaining to aesthetics and usability of the VE and incorporated some of this feedback into the iterative design-evaluate-redesign cycle. Overall, these initial results indicated little difficulty in adapting to use of the HMD, no self-reported occurrence of side effects as determined by posttest interviews using the Simulator Sickness Questionnaire (SSQ)[22] and excellent performance on the stimulus tracking challenges.

Research Methodology

Following this user-centered design phase, we conducted a clinical trial that compared eight physician-referred males with ADHD (6–12 years of age) with 10 non-diagnosed male children. The groups did not significantly differ in mean age, grade level, ethnicity, or handedness and all children diagnosed with ADHD were currently taking stimulant medication as treatment for their condition. However, participants in the ADHD group were off medication during the testing period with all testing occurring between 9 AM and 11 AM prior to normal medication ingestion. Participants with ADHD were excluded from the study if they presented with comorbid autism, mental retardation, Full Scale intelligence quotient score <85, or head injury with loss of consciousness >30 minutes. These same exclusion criteria were applied to the normal control group. Research participants were instructed to view a series of letters presented on the blackboard and to hit the response button only after he viewed the letter "X" preceded by an "A" (successive discrimination task). The stimuli remained on the screen for 150 milliseconds, with a fixed interstimulus interval of 1,350 milliseconds. Participants were instructed to press a wireless mouse button as quickly and accurately as possible (with their dominant hand) upon detection of an X after an A (correct hit stimuli) and withhold their response to any other sequence of letters. Four hundred stimuli were presented during each of two 10-minute conditions. The two 10-minute conditions consisted of one without distraction and one with distractions (pure audio-classroom noises, pure visual-paper airplane flying across the visual field and mixed audiovisual-a car "rumbling" by the window, and a person walking into the classroom with hall sounds occurring when the door to the room was opened). Distracters were each displayed for 5 seconds, and presented in randomly assigned equally appearing intervals of 10 seconds, 15 seconds, or 25 seconds and 36 distracters (nine of each) were included in the 10-minute condition. As well, six-degree-of-freedom tracking from the head, arm, and leg was used to produce movement metrics needed to analyze the motor hyperactivity component of this disorder. VR performance was also compared with results from standard neuropsychological testing, although this data is not presented here as it is currently being written up as part of full submission focused on this particular experiment.

SUMMARY OF INITIAL VIRTUAL CLASSROOM RESULTS

- No significant side effects were observed in either group based on pre- and post-VR SSQ testing.
- Children with ADHD had slower correct hit reaction times compared with normal controls on the distraction condition (760 milliseconds versus 610 milliseconds; $t(1,16)=-2.76$, $P<.03$).
- Children with ADHD had higher reaction time variability on correct hits compared with

normal controls on both the no-distraction (SD=220 milliseconds versus 160 milliseconds; $t(1,16)=-2.22$, $P<.05$) and distraction conditions (SD=250 milliseconds versus 170 milliseconds; $t(1,16)=-2.52$, $P<.03$).

- Children with ADHD made more omission errors (missed targets) compared with normal controls on both the no-distraction (14 versus 4.4; $t(1,16)=-4.37$, $P<.01$) and distraction conditions (21 versus 7.2; $t(1,16)=-4.15$, $P<.01$).

- Children with ADHD made more commission errors (impulsive responding in the absence of a target) compared with normal controls on both the no-distraction (16 versus 3.7; $t(1,16)=-3.15$, $P<.01$) and distraction conditions (12.1 versus 4.2; $t(1,16)=-3.22$, $P<.01$)

- Children with ADHD made more omission errors in the distraction condition compared with the non-distraction condition (21 versus 14; $t(1,16)=-3.50$, $P<.01$). No such differences on omission and commission errors were found with the non-diagnosed children across no-distraction and distraction conditions.

- Exploratory analysis of motor movement in children with ADHD (tracked from head, arm and leg) indicated higher activity levels on all metrics compared with non-diagnosed children across both conditions.

- Exploratory analysis of motor movement in children with ADHD also indicated higher activity levels on all metrics in the distraction condition compared with the non-distraction condition. This difference was not found with the normal control children.

DISCUSSION OF INITIAL VIRTUAL CLASSROOM RESULTS

These data suggested that the Virtual Classroom had good potential as an efficient, cost-effective and scalable tool for conducting attention performance measurement beyond what exists using traditional methodologies. The system allowed for controlled performance assessment within an ecologically valid environment and appeared to parse out significant effects due to the presence of distraction stimuli. Additionally, the capacity to integrate measures of movement via the tracking technology further added value to this form of assessment when compared with traditional analog tests and rating scales. In this regard, a HMD appeared to be the optimal display format. Although one of the common criticisms of HMD technology concerns

FOV limitations, in this application the limited FOV fostered head movement to supplement eye movement as the primary method for scanning the Virtual Classroom. This type of "poor-man's" tracking of behavioral attention within the controlled stimulus environment obtained in the HMD allowed for ongoing documentation as to where the user is "looking" during test content stimulus delivery. For example, a child missing a target while directly looking at the blackboard is illustrating an attentional error that is fundamentally different from the occurrence of a missed target due to the child looking out the window at a distraction. The documentation provided by head tracking in a HMD can be used to produce metrics of % time on task during stimulus "hit" trials as well as allowing for a re-creation of a naturalistic behavioral performance record for later review. In the current research, children with ADHD were found to miss targets due to looking away from the blackboard during 25% of the "hit" trials as opposed to normal subjects who were documented to be looking away at <1% of the time. This form of integrated cognitive/behavioral performance record of attention performance during delivery of systematic distraction is simply not obtainable using other methods. More detailed information on the rationale, methodology, and long-term vision for this project can be found in the reports by several researchers.[23,24]

Based on the initial results of this work an advanced version of the Virtual Classroom using more sophisticated graphics and system architecture was created (Figure 2). This version is now capable of delivering over 20 different types of distractions and allows for flexible building of distraction stimulus delivery profiles in addition to default scenarios that will be supported with normative data for comparisons across age and gender. Further, this functionally relevant "archetypical" environment was designed to be easily "retooled" for service to address other clinical targets and application areas. Since the creation of the latest version of the Virtual Classroom, multisite clinical tests have been conducted and, thus far, the results of this testing has replicated the initial findings from the original Virtual Classroom (A.A. Rizzo, PhD, et al., unpublished data, 2005). Results from those studies are currently being written up along with an update on the expanded clinical trials that are currently being designed for a series of pharmacologic trials.

DEVELOPMENT OF OTHER CLINICAL APPLICATIONS USING THE VIRTUAL CLASSROOM

Expansion of Attention Process Assessment Tasks: The Virtual Stroop Test

Researchers at the University of Victoria have conducted tests with the Virtual Classroom investigating complex attention performance using a virtual version of the Stroop test.[24] The Stroop effect is one of the most well established phenomena demonstrating interference control. The Stroop uses a color-word conflict design that requires the inhibition of a prepotent response to read color names when instructed to name conflicting ink colors.[25] There have been a plethora of different Stroop paradigms, but this is the first Stroop task to be designed and used within a VE (Figure 3) and the purpose of this initial study was to assess the validity of a Stroop task given in a VR classroom. The Virtual Classroom allows for a more controlled testing environment and reduces variability by controlling the participant's FOV and limiting the effects of unexpected visual and auditory distracters. It was hypothesized that the VR Stroop would produce "interference effects" similar to the classic paper and pencil format Stroop task. Eighty-one first-year psychology students (25 males, 56 females), between 17 and 33 years of age from the University of Victoria participated. The VR Stroop consists of two tasks. In the first task, colored boxes randomly appeared on the "chalkboard," and in the second task, color words written in different colors of chalk appear randomly on the chalkboard. In the second task, the stimuli are either "congruent" (eg, the word "RED" appears in red chalk), or "incongruent" (eg, the word "RED" appears in blue chalk). For each task, the virtual teacher stated a color as the stimulus appears on the board. The participant was instructed to click their mouse if the teacher's response correctly names the color of the chalk regardless of the actual color word.

Repeated measures analysis revealed mean reaction times (MRT) to colored boxes was significantly faster than MRT to congruent word stimuli, and both were significantly faster than MRT to incongruent word stimuli. The results demon-

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FIGURE 2.
Scenes from the advanced prototype of the Virtual Classroom

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FIGURE 3.
Scenes from the Stroop test, an interference attention task

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strated that a Stroop test administered in a VR environment can produce "interference effects" similar to a classic Stroop task. As expected, the colored boxes required no interference control, and thus reaction times to these stimuli were the fastest. Responses to the congruent word stimuli were more cognitively demanding than responses to the colored boxes, and thus MRT was slower than that to boxes, but faster than that to incongruent word stimuli. The incongruent word stimuli were the most cognitively challenging, requiring interference control, and, as expected, produced the longest MRT. The reaction times to the VR Stroop were slower than those typically found in response to a classic Stroop task. This is believed to result from the extent of cognitive processing necessary to complete the VR Stroop task. Specifically, participants must process the pictured stimulus as well as a verbal stimulus (teacher's response), and then determine if the teacher's response "matches" their own before making a response. Research to investigate these effects in more detail is currently underway.

Wide Field of View System to Study Eye Tracking Under Distracting Conditions in Children with Attention-Deficit/Hyperactivity disorder

In collaboration with the VR research group at St. Anselm College in New Hampshire,[27] the Virtual Classroom has been configured to be displayed on an Elumens VisionStation® (Figure 4). This research is evaluating the combination of the scenario and display system integrated with

FIGURE 4.
Virtual Classroom displayed on an Elumen's VisionStation® with eye and head tracking

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head movement and eye-tracking technology.[27] The use of the Virtual Classroom with this display and response capture system provides a testbed for comparing performance in this non-HMD, wide FOV system with findings from the original HMD application. If concordant results are found between these systems, such findings would lend support for the use of the lower-cost HMD method in spite of its limited FOV. Alternatively, added performance information from the eye-tracking data acquired in the VisionStation® application, would be useful in its own right and could enhance our understanding of visual scanning behavior in persons with ADHD. Previous research has suggested that evaluation of eye-tracking may be useful in a VE,[28] predicted it to be a good measure of sustained attention[29] and found eye-tracking algorithms to be useful for correctly classifying adolescents with ADHD.[30]

Thirty-six boys (8–14 years of age) have participated in this research to date. Nineteen were diagnosed with ADHD, and 16 served as non-diagnosed control subjects. Following informed consent and assent, a technician placed the View Eye X Tracking System helmet on the participant's head and the eye tracker was calibrated and the SensoMotoric Instruments system recorded participants' eye movement within the Virtual Classroom. Participants were placed in front of the VisionStation® and the Virtual Classroom vigilance task was then administered followed by a standard continuous performance attention task delivered on a flatscreen computer monitor. During testing, the subject's parents filled out a demographic questionnaire and The Behavior Assessment System for Children (BASC) parent report form.[31] The BASC is a behavioral rating scale consisting of four subscales: attention problems, hyperactivity, internalizing problems, and adaptive skills.

For the ADHD group, a strong correlation was found between overall scores on the Virtual Classroom and the flatscreen test, as well as on the attention problems subscale of the BASC. However, the attention problems subscale of the BASC did not correlate with the flatscreen test. In addition, the ADHD group performed significantly poorer than controls on overall scores and had more omission errors in the Virtual Classroom (similar to results found in previous tests with the HMD system). Eye-tracking analysis revealed the ADHD group was more likely to look off task when the cue (the letter A) appeared on the board than

the control group. Future research will investigate eye-movement data with free and cued recall of aspects of the Virtual Classroom and its relationship to galvanic skin response measures, teacher behavior ratings and classroom observation data.

The Virtual Classroom as a Tool for Anxiety Assessment and Exposure Therapy in Children and Adolescents with Social Anxiety Disorder

Researchers from the Child Study Center at the Virginia Polytechnic Institute are now commencing tests of the Virtual Classroom with children and adolescents diagnosed with social anxiety disorder (SAD). SAD is characterized by a marked and persistent fear of social or performance situations in which embarrassment or humiliation might occur. Children and adolescents with SAD report substantial distress across many social situations, including public performances (reading or reciting in front of others, performing in a play) and ordinary social interactions (starting conversations, joining in on conversations, talking to adults, or talking on the telephone). Frequently, when exposed to possible scrutiny by others, youths with SAD fear they might do something or act in a way that will be embarrassing or humiliating and this creates substantial distress for the majority of children with this disorder.[32] The classroom represents a context in which socially anxious children and adolescents typically experience their greatest struggles and consequences.[33] Accordingly, their reactions in a virtual classroom setting could provide data that

is relevant for determining a diagnosis of social anxiety disorder, provide assessment data for determining outcomes following various cognitive-behavioral interventions and for the actual delivery of graduated exposure therapy.

The Virtual Classroom is now undergoing initial user trials for the assessment of SAD in children and adolescents. This adaptation of the Virtual Classroom environment, incorporating specific situations relevant for school related activities, represents a much-needed link between laboratory and situational (in vivo) based assessment. Applied in this format, the user is positioned in the front of the Virtual Classroom and given a set of open-ended topics that they are asked to "speak about" to the class. Initial physiological and self-report data is being collected in order to determine anxiety and reactivity to the stimuli in the current classroom (Figure 5). Contingent on these results, the scenario will be modified to include the capacity to control the number of virtual students in the classroom audience as well as their "behavior" in terms of activity and direct gaze levels.

Earthquake Safety Training with Persons with Developmental and Learning Disabilities

Researchers at Aristotle University of Thessalonika in Greece, are about to begin test trials using an expanded version of the Virtual

FIGURE 5.
Virtual Classroom perspective from the front of the class as applied in initial user trials with children diagnosed with social anxiety disorder

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FIGURE 6.
Virtual Classroom expansion to include hallways/outdoor schoolyard for earthquake safety training

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Classroom for earthquake safety training in children with developmental and learning disabilities. Children with these forms of disability often have cognitive impairments that limit the degree to which they can learn from traditional reading and lecture methods. Procedural learning "by doing" trials within a VE may address this challenge. The design of this scenario included an expansion of the classroom to include a series of school hallways and part of an exterior schoolyard (Figure 6). The classroom interior is populated with 12 students and a teacher, each capable of realistic emotive responses to an earthquake situation, such as showing fear, communicating distress to varying degrees and movement around the classroom. When an earthquake event is triggered, the virtual humans respond appropriately, items in the VE respond with some degree of physics, and the environment shakes along with the appropriate sound effects. Safety training will be provided via two basic modes of interaction—a guided "storytelling" mode and an interactive mode, where the participant controls his or her navigation/actions during and in the aftermath of a simulated earthquake. An interface is being developed to allow the researcher to observe and record the users' actions as they navigate through the VE during training trials and these components are currently under construction.

CONCLUSION

The use of VR as a tool for assessment, therapy, and rehabilitation is expected to grow as the medical and psychological sciences evolve in the digital age. As with any technology applied in these areas, both challenges and opportunities will emerge in how virtual reality is usefully applied and validated.[34] The application of the Virtual Classroom scenario for attention process assessment in children with ADHD illustrates one area where this technology can add value over existing traditional methods. As well, the retooling of this VR system for other clinical purposes demonstrates one approach for how this technology can be applied in a cost-effective manner. The development of such archetypical VEs (ie, offices, homes, social environments, etc.) will likely continue as VR is applied to a wider range of clinical and scientific research questions in the future. **CNS**

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