Technology and Applications for Collaborative Learning in Virtual Reality

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Abstract: In this symposium we explore the immense potential for virtual reality to be applied in educational settings. We discuss recent technological developments against a backdrop of several decades of research. Six presentations, including four from academic authors and two from the commercial sector, will explore user requirements, new technologies, and practical issues in collaborative VR applications for learning.

Focus and issues addressed

Virtual reality has long been touted for its potential to revolutionize education, with myriad advantages cited: access to remote experts, access to experiences that depend on scarce or access-limited resources (e.g. going to the moon), and access to experiences that are physically impossible (e.g. such as standing inside a molecule), to name a few. A new generation of consumer hardware has made this vision more in-reach than ever. In this symposium our interest is to understand what advantages of virtual reality in an educational context could or should bring it into practice in the classroom, and what factors will determine when and how this will happen.

Advantages named for collaborative virtual environments fall into two broad categories: those focused on the interaction with other humans, and those focused on the environment. The human interaction may be novel because of *who* one can interact with (e.g. remote people), or *how* one can interact (e.g. taking on a different physical appearance). The environment may be novel because it is based on a physical place that only few people can go, or because the experience it provides is inherently virtual (e.g. standing inside a molecule). In this symposium we present research that sheds light on past, present, and future efforts to realize these advantages in different contexts. The first presentation will provide a brief history of virtual reality and its applications to learning, culminating in the most recent wave of technology. The presentation of Cobb et al. will describe the application of non-immersive collaborative virtual environments to education of students with autism. In this case, the virtual environment provides a novel kind of interaction that is "safe" and structured in ways that the physical world is not, and this is leveraged in order to train social competencies such as collaboration. The presentation of Gouveia et al. will center around the successful introduction of a different kind of interactive technology in the classroom -- namely simulation-based virtual labs -- that provide a novel non-immersive virtual environment. Parallels will be drawn in order to shed light on what factors may determine the success of introducing virtual reality in the classroom in the coming years. The presentation of Kulik et al. will discuss technology-based research around multi-user interactions in novel immersive environments. This research has attempted to identify and support the most important attributes of collaborative group work in these settings. The presentation of Holland and Buessing will share early results from a large-scale effort to bring immersive collaborative virtual reality to the classroom. Finally, the presentation by Greenwald et al. will present technology-based research that explores non-verbal communication, collaborative creative expression, and the learning of abstract physical concepts in an immersive virtual environment. By bringing all of these threads of research together in a symposium, we hope to gain a clearer understanding of the landscape of challenges and opportunities related to virtual reality in formal and informal learning settings.

Then and now: Positioning a new wave of research on VR and learning

Scott W. Greenwald, Victoria Lee, and Alexander Kulik

This presentation provides a brief history of the technology and applications of virtual reality in the past several decades, including many involving training, education, and collaboration. The first wave of modern virtual reality took place during the 1960s. Philco Corporation created the first head-mounted display named "Headsight" which had a screen and tracking system and was linked to a closed-circuit TV. The intent behind "Headsight" was to train military personnel in tasks such as landing a high-speed aircraft, chemical and hazardous tests which could be watched from afar, or controlling a highly maneuverable submarine (Philco Corp, 2016). Although it was not connected to a computer, "Headsight" pioneered the practice of leveraging virtual reality technology for learning and training purposes. Soon thereafter, Ivan Sutherland developed the first head mounted stereo display to link with a computer instead of a camera to display images (Sutherland, 1968).

In the mid-1970s Myron Krueger created an interactive physical environment called "Videoplace" (Krueger). Instead of head-mounted displays, "Videoplace" used projectors and video cameras to support interaction, through the onscreen silhouettes of users. "Videoplace" demonstrated the potential of virtual environments for artistic and creative expression. Around the same time, the Wright-Patterson Air Force Base in Ohio continued what "Headlight" had begun, experimenting with virtual reality simulations for training and education. By the late 1980s, they had launched the "Super Cockpit" program, a virtual cockpit to train pilots (Lowood, 2016). Shortly after "Super Cockpit", NASA's Johnson Space Center began using head mounted display-based VR simulations to prepare astronauts. Although virtual reality was not widely adopted commercially following projects such as these, it played a crucial role in learning and training in these and several other niche areas, including further military applications, medical research, and other academic research.

Collaborative virtual environments (CVE) have a long history as well. Churchill and Snowdon published a thorough introduction to the topic in 1998 (Churchill 1998). They detailed the nature of collaborative and cooperative activities, and analyzed the realization of such behavior within networked virtual environments, using several examples from the time. Referring to research on behavioral psychology, they emphasized the relevance of nonverbal communication and indicated how this could be achieved in shared virtual environments - even using desktop-based systems with third-person viewpoints. Apparently, many learning goals can be effectively achieved in such settings (Dede, 1995; Cobb et al. 2010). Dede even argued that the synthetic and anonymous qualities of these early CVEs could have a positive effect on constructivist learning. However, this type of system was adopted more widely in entertainment rather than learning applications. Puppeteering a 3D avatar and monitoring others on a computer screen is less direct and intuitive than equivalent activities in an immersive 3D space. The attentional load required to operate the interface ties up cognitive resources that could otherwise be used for primary activities, such as learning. However, early collaborative immersive VR systems generally did not support embodied interaction and head-tracked egocentric viewing. One reason was that head-mounted displays hindered the perception of one's own body and those of others, while large 3D displays generally supported only a single stereo view.

A few early research prototypes implemented collocated collaborative augmented reality systems, where the virtual 3D content is spatially aligned with the physical interaction space. The "Studierstube", for example, used see-through head mounted displays for this purpose. A group of users could see the same 3D model and interact with it in context of their real environment (Szalavari et al., 1998; Schmalstieg et al., 2002). Hua et al. equipped multiple users with head-mounted projectors (Hua et al. 2003). The walls of their interaction space were covered with retroreflective materials such that each user saw their own personal perspective. Both projects also explored the use of multiple independent viewing windows to support varying levels of collaborative coupling.

Projection-based 3D display technology provides a different approach that has been extended for collaborative use as well. The two-user "Responsive Workbench", for example, showed four different images in sequence on a CRT projector at 144Hz (Agrawala et al., 1997). Barco combined time sequential image separation with polarization for two users with individual views at their "Virtual Surgery Table". The approach was later improved with shuttered LCD-projectors supporting up to four users (Fröhlich et al., 2005) and more recently with a DLP-based system supporting up to six users (Kulik et al., 2011). Moreover, several special-purpose multi-viewer displays have been proposed, based on separate display regions for each user's stereo view (Arthur et al., 1998; Kitamura et al., 2001; Bimber et al., 2001; Mulder and Boschker, 2004). The drawback of this approach is that it leads to a very small collaborative interaction space.

These and other systems have powered more recent studies that seek to better understand human behavior, learning, and collaboration. A few examples include: how a virtual learning environment benefits education (Huang et. al.; 2010), how virtual reality encourages helping behavior and interpersonal understanding (Ahn et. al., 2013), or the effectiveness of virtual reality and overcoming phobias (Garcia-Palacios et al., 2002).

In the past several years, virtual reality technology has experienced a resurgence. Innovations in the design and manufacturing of the relevant devices has led to the availability of cheap and robust VR hardware, including wide field-of-view, high-resolution headsets and submillimeter precision tracking technology. As of 2016, there were 43 million active users of virtual reality and that number is forecasted to grow, reaching 171 million by 2018 (Statista, 2016). When the era of personal computing expanded in the 1990s, a new generation of users, developers, and researchers emerged, and we propose that there is a parallel with what is happening now with virtual reality. Given the prior success of virtual reality in education and training for niche applications, we believe that the broader exploration of use cases, enabled by the new generation of hardware coupled with the power of the internet, will result in many more successes. It will empower educators and learners with new tools and a new medium, improving communication, collaboration, and co-creation.

Collaborative virtual reality for joint learning experiences

Alexander Kulik, André Kunert, Stephan Beck, Bernd Fröhlich

Virtual reality systems promote situated learning through the immersive experience of interactive objects, environments and processes. Egocentric 3D viewing supports self-paced data exploration and bears the potential to increase the users' identification with the topic at hand. However, head-mounted displays also decouple users' from the perception of their own body and their immediate physical and social environment. This in turn can hinder the comprehension of the displayed content. For example, it is commonly understood that depth perception is disturbed in virtual environments. However, representations of self and the immediate physical environment have been shown to ameliorate this effect (Interrante et al., 2008; Mohler et al., 2010; Phillips et al., 2010). Perhaps, comprehension can be understood as the establishment of robust relations between oneself and the topic of interest.

Moreover, learning is largely driven by exchange with peers. This can be particular relevant, if it comes to the interpretation of complex and ambiguous information. The immediate exchange between students can help to consider multiple perspectives and also to confirm the most probable interpretations. Direct interaction and mixed-initiative communication promote the ongoing discourse on a topic. We also learn by doing. Therefore, virtual environments for learning should be highly interactive. Ideally, multiple learners can interact jointly with the virtual environment and thereby reinforce their understandings. Support for joint action, however, must consider several planned and emergent coordination processes, all of which build on the spatiotemporal coherency of the shared interaction space (Knoblich et al., 2011). Gutwin and Greenberg highlighted how people achieve the necessary workspace awareness in physical environments through consequential communication, feedthrough, and intentional communication (Gutwin & Greenberg, 2002).

We believe that the unmitigated perception of self and others is a prerequisite for effective comprehension, learning and exchange. Therefore, we developed projection-based virtual reality systems that do not limit the users' perception of their immediate surroundings (i.e. workspace awareness), but that additionally provide them with multiple individual viewpoints towards a shared 3D scene (Kulik et al., 2011). The result is a coherent mixed reality of virtual objects, environments, and multiple collaborating users. We observe that direct mutual exchange about the digital content increases their relevance for users and supports mutual confirmation (Figure 1). Our studies show that users can build on body language and deictic gestures just as they do with real world objects and that collaborative visual search increases the understanding of all involved users (Salzmann et al., 2009; Kulik et al., 2011).

More recently, we extended these systems with support for remote collaboration of groups (Beck et al., 2013). Our group-to-group telepresence system captures users in real-time with clusters of color and depth cameras. The data is then transmitted over the network and the users can be reconstructed at life size in the shared virtual environment. These 3D video avatars are far from perfect, but they are perceived as an authentic dynamic representation of the remote collaborators' activities and appearances, which does not seem to induce uncanny feelings among participants. Our study showed that body language, in particular, deictic gestures and those to manage turn taking can be well supported with such a system. However, in direct comparison with collocated collaborators, the perceived co-presence of these avatars is limited (Figure 2). We are planning to study the effects of such mediators on social behavior and the effectiveness of collaborative learning with remote participants in virtual environments.

Figure 1. Two users discussing details of a combustion engine using a box-shaped cross section view.

Figure 2. Collaborative wayfinding in a telepresence setting. The remote user is captured and represented as a 3D video avatar in the virtual environment. (Vianden Castle model courtesy of ArcTron 3D)

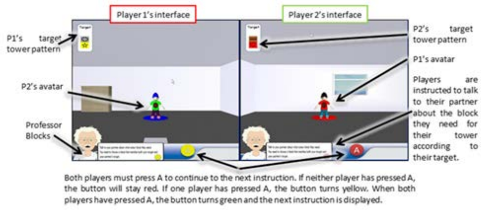
As most collaborative actions, also learning requires certain levels of individual autonomy. It has been shown, for example, that brainstorming sessions can be ineffective if the setting does not allow participants to work alone and take individual responsibility (Sawyer, 2008, pp. 64-66). Therefore, interfaces for multi-user cooperation should support fluent transitions between individual activities and varying levels of collaborative coupling. Loose coupling can increase the diversity of contributions, while tight coupling is required to achieve mutual agreement and convergence towards intermediate resolutions. Support for territoriality as an emergent social behavior seems to be a pragmatic, yet powerful, design principle in that regard (Scott et al., 2004). User interfaces for collaborative learning should thus provide multiple interaction areas and support dynamic spatial restructuring (Figure 3; Kunert et al., 2014).

Figure 3. A large 3D powerwall (back) and a multitouch 3D tabletop (front) serve as independent multi-user 3D viewports into a shared virtual world. A virtual 3D display, or portal (center, with white frame), offers additional perspectives. The physical and virtual viewports serve for private interaction and group exchange.
Their combination in a coherent workspace supports fluent transitions between tightly and loosely coupled cooperation. Here, a multi-scale 3D scan of prehistoric rock art and its environment (Valcamonica, Italy) is explored.

Designing collaborative virtual environments for interaction and learning in children with autism.

Sue Cobb, Sarah Parsons, Nigel Newbutt

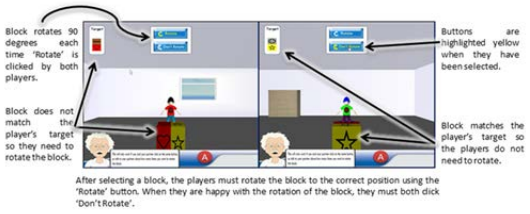
This presentation will use examples drawn from projects where we have developed applications using virtual reality technologies (VRTs) for children with autism. We plan to provide a context to the work we have completed in addition to a critical reflection and evaluation of involving stakeholders (teachers, students, related professionals) in the co-design and production of the materials, which are intended to be used in schools. The first project, COSPATIAL (2009-2012), developed collaborative virtual environments to encourage participation in social communication and collaboration amongst young people with autism. We focus on the Block Challenge game designed specifically to support student pairs in communicative perspective-taking and reciprocal co-operation in a collaborative block building task [Figure 1 and Figure 2] (Cobb et al. 2010) and present findings from an intervention study which suggest that CVEs can provide an educational context for learning and rehearsal of social communication, perspective-taking and reciprocity that can be effectively scaffolded by teachers (Parsons, 2015). The second project, VIRTAUT (2010-2013), sought to design a virtual world that would enable social skill opportunities, collaboration and participation in a virtual world via avatars and was implemented in a classroom-based setting [Figure 3 and Figure 4] (Newbutt, 2014). We will draw out specific examples where stakeholder involvement shaped the design and practice of using the virtual worlds in the classroom, was built in and the nature of working with autistic children.



Players are instructed to talk to their partner about the block they need for their tower according to their target.

Both players must press A to continue to the next instruction. If neither player has pressed A, the button will stay red. If one player has pressed A, the button turns yellow. When both players have pressed A, the button turns green and the next instruction is displayed.

Figure 1. Each payer has a separate screen interface displaying their own avatar perspective within the virtual environment and the target block tower pattern that they need to build.


Block rotates 90 degrees each time 'Rotate' is clicked by both players.

Block does not match the player's target so they need to rotate the block.

Buttons are highlighted yellow when they have been selected.

Block matches the player's target so the players do not need to rotate.

After selecting a block, the players must rotate the block to the correct position using the 'Rotate' button. When they are happy with the rotation of the block, they must both dick 'Don't Rotate'.

Figure 2. Building the tower to satisfy the different target patterns for each player requires communication, negotiation and collaborative interaction between the players.

Figure 3. The VIRTAUT collaborative virtual world provided a safe context for social interaction and communication between players.

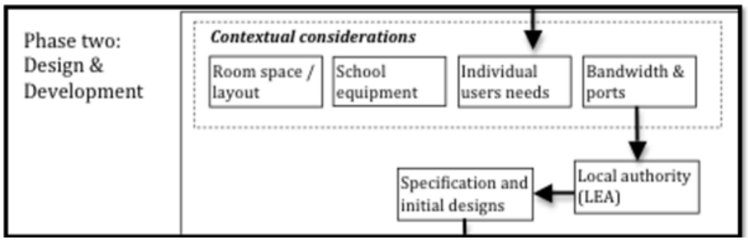


Figure 4. Involvement of educational stakeholders including both the school and local educational authority was important to identify contextual considerations to inform effective design.

In each of the projects the design process involved a variety of stakeholders each with different perspectives and objectives for the project outcomes. We will describe and reflect on the application of the 3T model of learner-centred design that determines CVE design based upon relevant learning Theory, Technology affordances and Thoughts (stakeholder-informed requirements) as a suitable framework to inform the design and development of educational technologies (Parsons and Cobb, 2014). In addition, the process of co-design identified various technological challenges with applying VRTs in situ (Newbutt, 2013). We will consider the opportunities and challenges of designing innovative technologies for special education, and specifically the affordances of VRTs for autistic user groups. In doing so we will consider ways to navigate these challenges and some best practice we have identified in design CVEs across the projects identified above. We hope to also highlight aspects of the design process that led to supporting interactions and learning in VR spaces. Future directions and priorities for research in this area will be presented.

"Nice to Have" to "Can't Do Without": Aligning simulations and VR with current needs in the K-12 classroom

Christine Gouveia, Claire Cook, Anne Snyder, and Scott Payne

How can immersive VR technologies be meaningfully and effectively incorporated into K-12 classroom instruction? To explore this question, we turn to a recent innovation that is closely related to immersive VR -- simulation-based lab activities for science instruction -- as an example of a technology that has been successfully integrated. Using these simulations as a case study, we examine the factors that have led to this success, and consider how they may inform the future of immersive VR technologies in a classroom context (Merchant et al., 2014; De Jong et al., 2013; Rutten et al., 2012; Toth et al., 2014).

For example, we ask: what learning experiences can a given technology enable that would not otherwise be possible using traditional approaches? Simulations and VR both have the potential to serve, not just as *adequate* substitutes for traditional / low-tech counterparts, but often as *superior* substitutes, when deployed in appropriate contexts and implemented in the right ways. We discuss the learning sciences research that both motivates and confirms the pedagogical value of simulations (and VR) for science learners; and we dig deeper into the practical considerations which help to propel its growing adoption among teachers. Among those practical considerations are those which bear on equity and access for K-12 learners. We argue that it is this parallelism between the pedagogical and practical which is key for an innovative alternative to take hold broadly and have staying power in a classroom context.

As developers continue to create and extend more sophisticated VR technologies, we survey the essential realities of the K-12 classroom that are important to consider, in order to ensure that emerging and evolving VR technologies solve a problem for users -- such that they will be broadly embraced and viewed as enabling essential learning experiences, rather than as fringe "add-ons" to more traditional curricula. We then invite participants to join us in examining what is perhaps the most important question of all: what problems can immersive VR technologies solve for K-12 teachers?

Principles, challenges, and lessons learned through developing a commercial platform for virtual reality in the classroom

Jennifer Holland and Shawn Buessing

Google Expeditions is a virtual reality teaching tool that lets you lead or join immersive virtual trips all over the world — get up close with historical landmarks, dive underwater with sharks, even visit outer space! Built for the classroom and small group use, Google Expeditions allows a teacher acting as a "guide" to lead classroom-sized groups of "explorers" through collections of 360° and 3D images while pointing out interesting sights along the way. We'll talk specifically about:

- Principles of educational content that we are finding effective for teachers of students
- Talk through why it's not easy to just repurpose legacy educational content into VR form and why many traditional educational publishers will have to rethink how they approach it
- Share specific examples and usage patterns in schools and countries
- Talk about specific hardware challenges with large group use of VR

Exploring same-time, same-place collaboration in room-scale virtual reality

Scott W. Greenwald, Wiley Corning, Gabriel Fields, Lei Xia

This presentation will summarize our explorations of same-time, same-place interaction in room-scale virtual reality with a focus on learning. As a baseline form of interaction, users are represented using minimal avatars in the virtual space in positions exactly corresponding to their actual physical positions. The avatars consist of semi-realistic representations of the headset and handheld controllers. The positions and orientations of these are updated to match their physical ones at 90Hz, giving their movement a very life-like appearance. My team has explored two different research questions related to this style of interaction. Firstly, we seek to understand the capacity of this medium (as described) to carry symbolic and emotive signals, typically carried not only by body gestures and movement, but also facial gestures and expressions. Second, we explore how one or more users can interact with and learn from simulation-based environments. This combination of questions is driven by the hypothesis that the combination of social and exploratory learning is particularly powerful in virtual reality.

We are currently developing an application, *CocoVerse*, which provides users with a suite of capabilities for creation and expression in a shared virtual environment. For example, users can draw volumetric shapes, add virtual objects and images to the environment and position them in space, write with speech-to-text, and take virtual snapshots and selfies. We structure this range of functionality within a set of discrete, easily-accessible tools, helping users to quickly learn and mentally compartmentalize the affordances available to them. In a learning application, teachers can lecture in 3D space for a live audience of students. Users can learn by interacting with simulated dynamics, or by exploring and annotating datasets or captured environments. Initial tests have shown the design to be learnable and usable. The modular codebase allows the application to be easily extended and customized to create domain-specific experiences, and we are collaborating with developers, instructors, and researchers to expand the set of use cases covered by our feature set, and identify cross-cutting design principles.

In order to explore how social learning works in a simulation-based environment, we selected a concrete use case -- a virtual reality physics environment, focused on university-level electricity and magnetism. The environment allows one or more people to explore the interaction of charged particles. In doing so, they gain insight into the dynamics of these interactions, as well as how these relate to the exact shape, form, and significance of the electric field generated by the particles. One of the general challenges in multi-user interactions with simulations is the sharing of control. In this case, where both users are free to place or drag charged particles in space, there are few conflicts to be concerned with -- the nature of the simulation lends itself to parallel interaction. One shared capability is the play/pause button that allows users to freeze the action of the system temporarily.

In our informal pilot studies, we identified some requirements related to the usage of such systems as a central element of curricular education. Although it is motivating and fun to interact with such a "playground," learners often require guidance in order to discover noteworthy phenomena or principles. We are exploring how to build scaffolding to balance guidance with self-direction for this use case.

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