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The Use of Immersive Virtual Reality in the Learning Sciences: Digital Transformations of Teachers, Students, and Social Context

Jeremy N. Bailenson and Nick Yee
Department of Communication
Stanford University

Jim Blascovich and Andrew C. Beall
Department of Psychology
Stanford University

Nicole Lundblad
Department of Symbolic Systems
Stanford University

Michael Jin
Department of Computer Science
Stanford University

This article illustrates the utility of using virtual environments to transform social interaction via behavior and context, with the goal of improving learning in digital environments. We first describe the technology and theories behind virtual environments and then report data from 4 empirical studies. In Experiment 1, we demonstrated that teachers with augmented social perception (i.e., receiving visual warnings alerting them to students not receiving enough teacher eye gaze) were able to

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Correspondence should be addressed to Jeremy N. Bailenson, Department of Communication, Stanford University, 450 Serra Mall, Stanford, CA 94305-2020. E-mail: bailenson@stanford.edu

spread their attention more equally among students than teachers without augmented perception. In Experiments 2 and 3, we demonstrated that by breaking the rules of spatial proximity that exist in physical space, students can learn more by being in the center of the teacher's field of view (compared to the periphery) and by being closer to the teacher (compared to farther away). In Experiment 4, we demonstrated that inserting virtual co-learners who were either model students or distracting students changed the learning abilities of experiment participants who conformed to the virtual co-learners. Results suggest that virtual environments will have a unique ability to alter the social dynamics of learning environments via transformed social interaction.

INTRODUCTION

Many researchers have investigated the viability of *virtual environments* (VEs), digital simulations that involve representations of teachers, students, and/or content, for learning applications. In this article, we describe how VEs enable *transformed social interaction* (TSI), the ability of teachers and students to use digital technology to strategically alter their online representations and contexts in order to improve learning. We present evidence from a series of empirical studies that demonstrate how breaking the social physics of traditional learning environments can increase learning in VEs. Of course immersive virtual reality currently is not yet an easily acquired technology in classroom settings. Nevertheless, VEs are becoming more common place, and it is important to understand how this digital technology will aid the basic learning process.

In this Introduction, we first provide a discussion of the taxonomies of VEs in general and previous implementations of learning systems in VEs. We next provide an assimilation of the literature on learning in VEs, focusing on the unique affordances provided by VEs not possible in face-to-face settings, including explicating our theory of TSI. Finally, we provide an overview of the current experiments.

Definitions and Taxonomies of VEs

VEs are distinct from other types of multimedia learning environments (e.g., Mayer, 2001). In this article, we define VEs as "synthetic sensory information that leads to perceptions of environments and their contents as if they were not synthetic" (Blascovich et al., 2002, p. 105). Typically, digital computers are used to generate these images and to enable real-time interaction between users and VEs. In principle, people can interact with a VE by using any perceptual channel, including visual (e.g., by wearing a head-mounted display [HMD] with digital displays that project VEs), auditory (e.g., by wearing earphones that help localize sound in VEs), haptic (e.g., by wearing gloves that use mechanical feedback or air blast systems that simulate contact with object VEs), or olfactory (e.g., by wearing a nosepiece or collar that releases different smells when a person approaches different objects in VEs).

An *immersive virtual environment* (IVE) is one that perceptually surrounds the user, increasing his or her sense of presence or actually being within it. Consider a child's video game; playing that game using a joystick and a television set is a VE. However, if the child were to have special equipment that allowed him or her to take on the actual point of view of the main character of the video game, that is, to control that character's movements with his or her own movements such that the child were actually inside the video game, then the child would be in an IVE. In other words, in an IVE, the sensory information of the VE is more psychologically prominent and engaging than the sensory information of the outside physical world. For this to occur, IVEs typically include two characteristic systems. First, the users are unobtrusively tracked physically as they interact with the IVE. User actions such as head orientation and body position (e.g., the direction of the gaze) are automatically and continually recorded, and the IVE, in turn, is updated to reflect the changes resulting from these actions. In this way, as a person in the IVE moves, the tracking technology senses this movement and renders the virtual scene to match the user's position and orientation. Second, sensory information from the physical world is kept to a minimum. For example, in an IVE that relies on visual images, the user wears an HMD or sits in a dedicated projection room. By doing so, the user cannot see objects from the physical world, and consequently it is easier for him or her to become enveloped by the synthetic information.

There are two important features of IVEs that will continually surface in later discussions. The first is that IVEs necessarily track a user's movements, including body position, head direction, as well as facial expressions and gestures, thereby providing a wealth of information about where in the IVE the user is focusing his or her attention, what he or she observes from that specific vantage point, and what are his or her reactions to the environment. The second is that the designer of an IVE has tremendous control over the user's experience and can alter the appearance and design of the virtual world to fit experimental goals, providing a wealth of real-time adjustments to specific user actions.

Of course there are limitations to IVEs given current technology. The past few years have demonstrated a sharp acceleration of the realism of VEs and IVEs. However, the technology still has quite a long way to go before the photographic realism and behavioral realism (i.e., gestures, intonations, facial expressions) of *avatars*—digital representations of one another—in IVEs approach the realism of actual people. Moreover, although technology for visual and auditory IVEs steadily develops, systems for the other senses (i.e., haptic) are not progressing as quickly. Consequently, it may be some years before the technology rivals a real-world experience. And finally, some users of IVEs experience simulator sickness, a feeling of discomfort resulting from the optics of particular technological configurations. However, a recent longitudinal study has demonstrated that simulator sickness is extremely rare today, given the speed of current tracking and graphics systems, and also that the effects for a given user tend to diminish over time (Bailenson & Yee, 2006).

Collaborative virtual environments (CVEs) involve more than a single user. CVE users interact via avatars. For example, while in a CVE, as Person A communicates verbally and nonverbally in one location, the CVE technology can nearly instantaneously track his or her movements, gestures, expressions, and sounds. Person B, in another location, sees and hears Person A's avatar exhibiting these behaviors in his or her own version of the CVE when it is networked to Person A's CVE. Person B's CVE system then sends all of the tracking information relevant to his or her own communications over the network to Person A's system, which then renders all of those movements via Person B's avatar, which Person A can see and hear. This bidirectional process—tracking the users' actions, sending those actions over the network, and rendering those actions simultaneously for each user—occurs at an extremely high frequency (e.g., 60 Hz).

Traditionally, researchers have distinguished *embodied agents*, which are models driven by computer algorithms, from avatars, which are models driven by humans in real time. Most research examining learning in VEs has utilized embodied agents (as opposed to avatars; see Bailenson & Blascovich, 2004, for a discussion). One reason for this disparity is that readily available commercial technology allowing individuals to create digital avatars that can look and behave in real time like the persons they represent has emerged only recently. Previously, producing real-time avatars that captured the user's voice, visual features, and subtle movements was quite difficult. Consequently, understanding the implications of the visual and behavioral veridicality of an avatar on the quality of interaction is an important question that has received very little empirical attention.

As the technological barriers to creating CVEs have decreased, a growing number of researchers have created CVEs specifically as educational platforms. For illustration, we discuss three implementation approaches with case studies. The first approach leverages observations that online games are highly engaging and attempts to create CVEs that reward activities performed offline. One well-known educational example is Quest Atlantis (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005), wherein students engage in a variety of "quests"—mostly offline tasks that vary in duration, domain, and complexity. Quests may require students to interview family and friends, research community problems, or produce advocacy media. By completing quests, students earn points and gain status in addition to privileges in the VE. In this sense, Quest Atlantis is a mixed platform—the VE provides a reward structure for tasks that largely need to be performed offline.

Another approach is to embed both the task and reward within the VE. An example is the River City project (Clarke & Dede, 2005), a multi-user VE for learning scientific principles and hypothesis testing built using design-based research. In River City, students interact with one another and the town's inhabitants via avatars using typed chat as they investigate and develop hypotheses regarding one of three strains of illness in the town. The researchers identified several experiences that exemplified "neomillennial learning styles" (p. 4). First, the environment created an immersive experience that allowed students to become shapers of a scientific experience rather than passive observers. Second, River City allowed students to shed an identity of a "'student failing science' and take on the identity of a scientist" (p. 5). And finally, the immersive experience also encouraged critical thinking by actively engaging students. It is worth noting that these three features would not be present in systems using the first approach, because the reward structure in and of itself does not provide these features.

A third approach has been to leverage existing online environments instead of creating them from scratch. For example, researchers from the University of California at Los Angeles collaborated with developers of the children's online environment Whyville to engineer a virtual pox epidemic in an attempt to increase awareness of and learning about epidemics and vaccinations (Foley & La Torre, 2004). The pox was spread by proximity and interaction. Vaccinations could be used to immunize against the pox, but a vaccination shortage (modeled from flu vaccine shortages in the real world) made it impossible for every user to be immunized. Users infected with the pox would occasionally sneeze (thereby replacing some of their typed chat), and spots would appear on their avatars' faces. Researchers found that the event led to a dramatic increase in users exploring the medical libraries in Whyville, and science topics in chat and message boards increased by 2000%. This comparatively informal approach illustrates how VEs could be used to increase interest and inquiry in specific topic areas.

Unique Affordances of VEs for Learning

Researchers in many disciplines (e.g., the learning sciences, computer science, psychology, communication) have studied the use of VEs for learning. The strongest case for VEs as learning modules stems from their ability to implement contexts and relationships not possible to achieve in a traditional learning setting. In this section we review a number of the unique learning opportunities VEs provide.

Embodied agents that teach and learn. One paradigm used in learning sciences seeks to create intelligent virtual agents who teach a learner about a specific domain (see Badler, Phillips, & Webber, 1993, for an early example; or Moreno, in press, for a recent review). For example, Rickel and colleagues have explored the use of virtual agents in teaching users how to perform complex mechanical tasks (Rickel & Johnson, 1998) as well as how to respond to crises in which both emotional and cultural factors have to be considered (Hill et al., 2003).

The latter study is noteworthy for implementing a natural language processing interface as well as producing agents that can behave and react with a wide range of emotional tones. A similar use of virtual agents that employ natural language processing can be found in work by Graesser, Wiemer-Hastings, Wiemer-Hastings, and Kreuz (1999), who created a virtual tutor for teaching the fundamentals of hardware and operating systems.

Work in this area has also explored virtual agents that encourage the construction rather than consumption of knowledge. For example, Cassell (2004) implemented a digitally augmented dollhouse that encourages children to tell stories as a way of promoting literary competencies. It is also worth noting that the virtual agent in this dollhouse is presented as a young boy, and thus this approach provides a learning paradigm whereby the user perceives the agent as a same-age playmate rather than an authoritative teacher. Similar work by Schwartz, Pilner, Biswas, Leelawong, and Davis (in press) has shown that when agents encourage students to teach them, learning improves as students process the information while teaching the agents. Virtual agents not only allow a user to enter into a learning experience at his or her own convenience, but they can also provide personalized one-on-one learning experiences tailored to the individual that would be prohibitively expensive otherwise (Baylor & Kim, 2005).

Co-learners. Although virtual teachers allow users to learn any time any where, one trade-off is that oftentimes users must give up the contextual environment of the classroom as well as other students. From a communities of practice point of view (Wegner, 1998), the absence of a social group of peers is a significant drawback to the typical individualized learning environments with virtual teachers. Indeed, students learning in social conditions (whether cooperative or competitive) outperform students in individualistic conditions (Johnson, Johnson, & Skon, 1979). And students studying with a partner remember more factual material than when studying alone (Wood, Willoughby, Reilly, Elliot, & DuCharme, 1995).

However, it is possible to populate a virtual learning environment with virtual co-learners (Kim & Baylor, 2006; Lee et al., in press). Moreover, research in interactive agents (Reeves & Nass, 1996) has suggested that people may respond to behaviors of a virtual co-learner similarly to how they respond to human co-learners in a virtual classroom. Thus, the aforementioned benefits of co-learners could conceivably be harnessed in VEs. And finally, virtual co-learners can be programmed to behave specifically to enhance each user's learning, something that cannot be done as easily with real students in a classroom.

Of course, it may be argued that much of the benefit from co-learners is due to dialogue or shared reasoning, an experience that is hard to create with virtual agents. However, some research has shown that co-learners can improve learning through their behaviors alone. In a study of virtual co-learners (Ju, Nickell, Eng, & Nass, 2005), it was found that varying a co-learner's behavior can enhance a user's performance. In Ju et al.'s study, users learned Morse Code alongside a co-learner. Users next to a high-performing co-learner performed significantly better themselves than users next to a low-performing co-learner. Thus, virtual learning environments provide unique opportunities to leverage the benefit of co-learners, whether through highly interactive agents that can provide a shared reasoning and dialogue experience, or via behaviors alone in a simpler system.

Visualizations. VEs can provide enhanced visualizations and a range of perspectives into complex information (Salzman, Dede, Loftin, & Chen, 1999). For example, the ability to create, alter, and rotate an architectural, engineering, or chemical structure in real time three dimension can make it easier to understand abstract concepts (Perdomo, Shiratuddin, Thabet, & Ananth, 2005).

In addition to providing visualizations of complex information, VEs also provide the ability to take on multiple perspectives of the same scenario. Studies have shown that different perspectives make salient different aspects of the same environment (Ellis, Tharp, Grunwald, & Smith, 1991; Thorndike & Hayes-Roth, 1982). For example, in Thorndike and Hayes-Roth's study on knowledge acquired from maps as opposed to navigation, it was found that maps allowed people to make better judgments of relative location and straight-line distance between objects, whereas navigation allowed people to more accurately estimate route distances. VEs can easily provide users with multiple perspectives on the same situation—central, peripheral, bird's-eye view, and so on—to make different aspects of the situation salient.

Finally, VEs can provide not only visual cues but, with the integration of other technologies, haptic and auditory cues. These additional cues can benefit learning in several ways. First of all, additional sensory cues provide a more realistic and engaging learning experience (Psotka, 1996). But more important, the addition of haptic cues allows users to acquire proficiency in activities that require eye–hand coordination, such as surgical skills. For example, a virtual training tool in surgical drilling with haptic feedback helped users perform an analogous task in a physical environment (Sewell et al., 2007).

Synthesis of archived behaviors. One of the great advantages of digital VEs is that every single action that is rendered (i.e., shown to the users) must be formally represented in order to appear to the users. Consequently, all actions performed by every single student or teacher, ranging from microbehaviors such as nonverbal gestures to macrobehaviors such as performance on an exam, can be constantly recorded over time. By storing and assimilating this data, VEs promise to provide a tool to create behavioral profiles and summaries on a scale not possible face to face.

For example, Rizzo and colleagues (2000) automatically collected the gaze behavior of students in a virtual classroom via head-tracking devices and used patterns of attention and gaze to diagnose deficits in attention among children. In a more complex and naturalistic learning environment, researchers utilized a network methodology to track the interaction among students and teachers over a 1-week period (Barab, Hay, Barnett, & Squire, 2001) and provided a framework for using historical data to map out the relationships between actions, conceptual understanding, and context. Finally, other researchers have utilized digital video as a way of archiving and tracing learning patterns through collaborative groups (see Roschelle, Pea, & Sipusic, 1989, for an early example). As the behavioral tracking systems become more elaborate, the ability to use this information to track student performance and consequently improve learning systems should become a major advantage of using virtual classrooms.

Presence, immersion, and learning. The construct of *presence* has often been used as a metric to evaluate the utility of a VE. Although there is no consensus on an exact definition of presence, the general notion concerns the degree to which the user actually feels as if he or she is present in the VE (as opposed to present in the physical world). Attempts at capturing the subjective experience of presence in an objective manner have proceeded along several different lines, including questionnaire ratings (Heeter, 1992; Held & Durlach, 1992; Short, Williams, & Christie, 1976; Witmer & Singer, 1998), physiological measures (Meehan, 2001), and behavioral measures (Bailenson, Blascovich, Beall, & Loomis, 2003; Mania & Chalmers, 2001; Welch, 1999). Despite broad research on the topic of presence, reliable measures are still lacking, and much debate as to how to quantify the construct exists (for various viewpoints, see Heeter, 1992; Lombard & Ditton, 1997; Loomis, 1992; Slater, 1999; Zahorick & Jenison, 1998).

One argument for using VEs in the classroom is that learners can feel more psychologically present in a virtual simulation than is possible in other types of traditional learning venues (Kafai, 2006; Kafai, Franke, Ching, & Shih, 1998). For example, researchers are demonstrating that when students actually experience learning material in an interactive video game context, they learn in unique manners (e.g., Barab et al., 2005). Similarly, by using IVEs, students can feel present in a virtual body that is not their own (Lanier, 2001). For example, work by Yee and Bailenson (2006) demonstrated that college-age students who are forced to take on the first-person visual perspective of a senior citizen in a VE develop more empathy toward elderly adults than students who take on the perspective of a young person. Finally, by using virtual technology to bring together large groups of students in the same virtual class (see Dede, Nelson, Ketelhut, Clarke, & Bowman, 2004, for a plausible short-term design strategy for such an environment), students may collaboratively experience course material in a way not possible from lectures, movies, or interactive problem-solving tasks.

Simulation of dangerous or expensive lessons. There is also a line of research using VEs to teach lessons that are either too expensive or too dangerous to conduct in physical space. For example, Stansfield, Shawver, Sobel, Prasad, and Tapia (2000) designed and tested fully immersive systems to train emergency response workers such as firefighters and bioterrorist response units. By using realistic virtual depictions of dangerous crises, learners can experience the chaos and affective stressors that are typically accompanied with actual crises. Similarly, there have been a number of studies that have used virtual simulations to train surgeons (see Sutherland et al., 2006, for a systematic review of this work). The advantage of virtual surgery training simulations is that cadavers, a natural alternative, are extremely rare and expensive, whereas virtual patients, once built, are extremely cheap to duplicate.

TSI. Recent research in the learning sciences has stressed the importance of understanding the social aspects of digital learning environments (Allmendinger, Troitzsch, Hesse, & Spada, 2003; Bielaczyc, 2006; Enyedy, 2003). Because CVEs render the world separately for each user simultaneously, it is possible to interrupt or distort the normal physics of social interaction and to render the interaction differently for each participant at the same time. In other words, the information relevant to a CVE participant is transmitted to the other participants as a stream of information that summarizes his or her current movements or actions. However, that stream of information can be transformed on the fly and in real time for strategic purposes. The theory of TSI (Bailenson, 2006; Bailenson & Beall, 2006; Bailenson, Beall, Loomis, Blascovich, & Turk, 2004) describes the potential of these real-time transformations. We discuss three dimensions for transformations during interaction: self-representation, social-sensory abilities, and social environment.

The first dimension of TSI is *self-representation*, the strategic decoupling of the rendered appearance or behaviors of avatars from the actual appearance or behavior of the humans driving the avatars. Because CVE interactants can modulate the flow of information, thereby transforming the way in which specific avatars are rendered to others, rendered states can deviate from the actual state of the interactant. For example, in a virtual learning paradigm, it could be the case that some students learn better with teachers who smile and some learn better with teachers with serious faces. In a CVE, the teacher can be rendered differently to each type of student, tailoring his or her facial expressions to each student in order to maximize that student's attention and learning.

The second dimension is transforming *social-sensory abilities*. These transformations complement human perceptual abilities. One example is to render *invisible consultants*, either algorithms or humans whose information is only visible to particular participants in the CVEs. These consultants can either provide real-time summary information about the attentions and movements of other interactants (information that is automatically collected by the CVE) or scrutinize the actions of the users themselves. For example, teachers using virtual learning applications can utilize automatic registers that ensure they are spreading their attention equally toward each student.

The third dimension is transforming the *social environment*. The contextual setup of a virtual meeting room can be optimally configured for each participant. For example, while giving a speech in front of an audience, the speaker can replace the gestures of distracting students with gestures that improve the ability of that speaker to concentrate. Furthermore, by altering the flow of rendered time of the actions of other interactants in a CVE, users can implement strategic uses of "pause," "rewind," and "fast forward" during a conversation in an attempt to increase comprehension and productivity.

Overview of Experiments

We report results from four preliminary experiments designed to demonstrate the utility of CVEs for studying learning sciences. All four studies utilized the paradigm of TSI to improve learning.

In Experiment 1 we utilized a transformation of social-sensory abilities, manipulating whether participants teaching a room of virtual students received cues warning them when any of the virtual students had been outside of the teaching participants' visual field of view. We predicted that teachers with this augmented perception would be able to more uniformly spread their mutual gaze than teachers with normal perception.

In Experiment 2 we utilized a transformation of social environment, specifically the location in a virtual classroom where participants sat while being presented with a verbal lesson from a virtual teacher. Because the CVE can be transformed differently for multiple learners simultaneously, it is possible for each of two students to both sit in the same place in a virtual room (i.e., an optimal location for learning) while believing he or she is the only student in that spot. Participants received two learning passages, one directly in the center of the teacher's visual field of view and one in the teacher's periphery. We predicted that students would learn the passage better when sitting in the center.

Experiment 3 was a replication of Experiment 2, manipulating the distance between student and teacher instead of the angle. We predicted students sitting closer to the teacher would learn better than students sitting farther away.

In Experiment 4 we transformed social environment by inserting virtual co-learners around a participant listening to a verbal lesson from a virtual teacher. The co-learners were either model students, paying attention to the teacher enthusiastically, or alternatively were distracting students who did not pay attention to the teacher. We predicted that students would conform to the behaviors of the co-learners and would learn more in the model student condition than the distracting student condition.

In all four of our studies, the learning process was operationalized as a teacher transmitting information via lecture to students who were tested on recall shortly thereafter. There has been much discussion concerning the ability of students to learn from traditional lectures delivered by an instructor (i.e., *telling models*; Smith, 1996) compared to a more active learning process in which students interact with people and materials (i.e., *constructivist models*; Cobb, 1994). As a whole, the field currently leans toward the constructivist model as the more optimal learning paradigm (see Baylor & Kitsantas, 2005, for a recent discussion). However, some researchers have been reconsidering the role of delivering information in the classroom. For example, Schwartz and Bransford (1998) provided evidence that telling via lecturing can be effective if the students have preexisting, well-differentiated knowledge about a given domain. Their results demonstrated that when students were trained to form sufficiently developed categories within a topic, they utilized lecture material effectively. More recently, Lobato, Clarke, and Ellis (2005) proposed that telling can be reformulated if researchers focus on the function of telling rather than the form, the conceptual content of telling rather than the procedural aspects, and the relationship of telling to other actions instead of telling in a vacuum. Their key insight was that telling can act as a mechanism to initiate other actions and consequently can result in effective learning if formulated properly.

In the current work, our goal is not to imply that the fundamental activity in teaching and learning is lecture and recall. Instead, we envision the telling process as merely a common component of many teaching approaches, including some that also include constructivist processes. By isolating components of teaching and learning, we are best able to test our theories of TSI in virtual reality. Ideal learning environments of the future are likely to blend both real interactions with virtual ones, as well as telling processes with active/constructive ones. However, before arriving at the optimal combination of component processes, we are beginning to test one individual component in the current work.

EXPERIMENT 1: AUGMENTED SOCIAL PERCEPTION AND EYE GAZE

Design

Participants in this study acted as teachers interacting in a virtual classroom with nine virtual students, each of whom exhibited prerecorded head movements. Two between-subjects variables were manipulated. The first variable was augmented social perception; a teacher either did or did not receive real-time information about his or her gaze behavior via the opacity of each student's digital representation. The opacity level of each student was directly related to the amount of gaze provided by the teaching participant, such that students would become increasingly translucent while out of the teacher's field of view. The second variable manipulated was requirement to lecture; participants either had to talk to the students during the length of the study, or they did not.

Participants

Forty undergraduate students (20 men and 20 women) participated in the study for course credit or pay. There were 10 participants in each of the four between-participants conditions resulting from crossing augmented social interaction (present vs. absent) with requirement to lecture (required vs. not required).

Materials

The virtual setting. The immersive, three-dimensional virtual classroom contained a long, slightly curved table behind which nine virtual student agents were seated, and a podium behind which the teacher (i.e., the participant) was standing (see Figure 1). Participants could see the student agents as well as their own torsos (if they looked straight down). We avoided using student agents whose faces were extremely attractive or extremely unattractive according to previously a pretested database (Yee & Bailenson, 2007).

Head movements of virtual students. We conducted a pilot study to collect realistic-looking head movements for the nine virtual students used in this study in order to ensure that the gazes of the students would be appropriate for the exact seat location setup of the room. In the pilot study, 36 undergraduate students (14 men and 22 women) listened to a recorded virtual teacher give an 8-min lecture about the pharmaceutical industry in the same virtual learning environment as was used in Experiment 1. Each participant was randomly assigned a seat in the classroom (out of the nine possible seats). The other eight student agents exhibited previously recorded realistic head movements. In the pilot study, 36 participant head movement sessions of 8-min in length were recorded: four different recordings for each of the nine seat positions. For the main study, we randomly selected one of the recordings from the pilot study for each of the nine seating positions so that the participant teaching the lesson could see realistic head movements of the student agents.

Apparatus

Figure 2 depicts a person wearing the HMD, which allows the participant to see and interact in the virtual world. The HMD contains a separate display monitor for

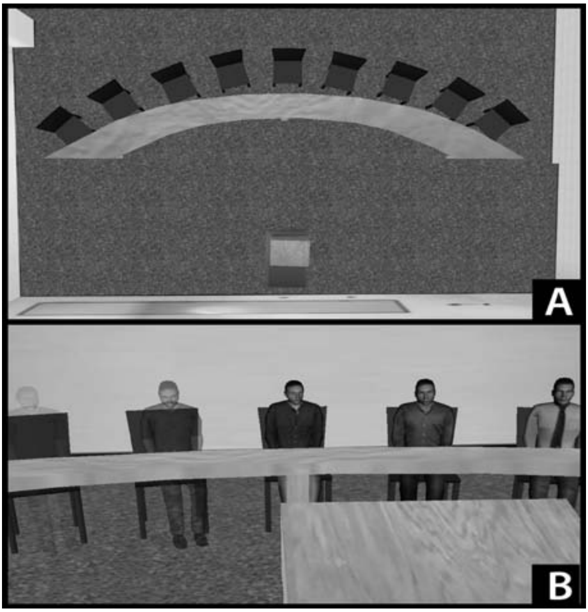

FIGURE 1 A bird's-eye view of (A) the virtual learning environment and (B) the specific viewpoint of a participant as he or she teaches the virtual class.

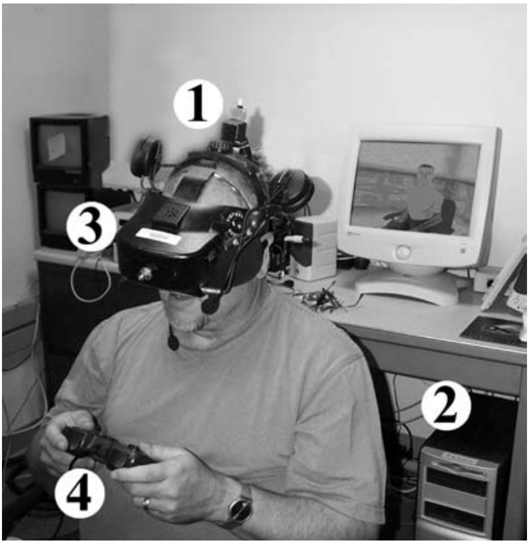

FIGURE 2 A simulated participant wearing the equipment: (1) head orientation tracking device, (2) rendering computer, (3) head-mounted display, (4) game pad used to record responses.

each eye (50° horizontal × 38° vertical field of view with 100% binocular overlap). The graphics system rendered the virtual scene separately for each eye (in order to provide stereoscopic depth) at approximately 60 Hz. That is, the system redrew the scene 60 times per second in each eye, continually updating the simulated viewpoint as a function of the participants' head movements, in order to reflect the appropriate movements. The system latency, or delay between a participant's movement and the resulting concomitant update in the HMD, was less than 45 ms. The orientation of the participant's head along the *x*, *y*, and *z* planes was tracked by a three-axis orientation sensing system (Intersense IS250, update rate of 150 Hz). The software used to assimilate the rendering and tracking was Vizard 2.53. Participants wore either a nVisor SX HMD that featured dual 1,280 horizontal × 1,024 vertical pixel resolution panels or a Virtual Research HMD that featured dual 640 horizontal × 480 vertical pixel resolution panels.

Procedure

When participants arrived at the laboratory, they were given paper instructions to read that differed according to the experimental condition to which they had been randomly assigned. Participants required to lecture were told they would have to lecture verbally and nonverbally with nine virtual students for 8 min, teaching them about certain topics, whereas participants not required to lecture were told they would only have to interact nonverbally with the nine students. Participants in the augmented social perception condition were told that students would fade in and out according to how much the participants looked at them. Participants in all four conditions were instructed that they should attempt to spread their eye gaze equally between all nine students:

> We are using this virtual reality simulation to examine how teachers use eye gaze to engage students while teaching. Given that students learn better while receiving eye gaze, it is helpful for teachers to spread their gaze among all of the students in a class. In this experiment, we want you to do your best to move your head around often in order to spread your eye gaze equally between all nine students.

After participants finished reading the paper instructions, they were shown how to wear and adjust the HMD. Once comfortable with the HMD, participants found themselves in a classroom, standing behind a podium in front of nine empty chairs placed behind a long, slightly curved desk (see Figure 1). When the participant indicated that he or she was ready begin, the experimenter began the experiment. At this point, the empty chairs were filled with the virtual students. At any given moment, participants could only see about a third of the virtual students due to the field of view of the HMD. If the participant had been assigned to teaching conditions, then prompts concerning different topics of discussion appeared in the top of the field of view and changed every 30 s. The participant was required to discuss each prompt with the students in the class. If the participant had not been assigned the conditions to teach, then no prompts appeared. If the participant had been assigned to the augmented social perception conditions, then the student agents changed opacity according to how much they were looked at by the participant, with a student degrading linearly from fully opaque to fully translucent in 15 s if kept out of the participant teacher's field of view. Although the students turned translucent, the chairs the students were sitting in remained opaque in order to ensure the teacher knew a student was supposed to be sitting there. If the participant had not been assigned to the augmented social perception conditions, then all of the students remained opaque the entire time. At the end of 8 min, participants removed the HMD and were thanked for their participation.

Results and Discussion

The main dependent variable was *gaze inattention*, or the amount of time students were completely kept out of the teacher's field of view. Figure 3 shows the percentage of time students were ignored as a function of the nine seats for the augmented social perception condition and the nonaugmented social perception condition. We collapsed the nine seats into the location variable: center seats (the five seats in the middle) and periphery seats (the set of four seats defined by the two on the outside left and the two on the outside right). We then ran an analysis of variance (ANOVA) with location as a within-subjects variable, augmented social percep-

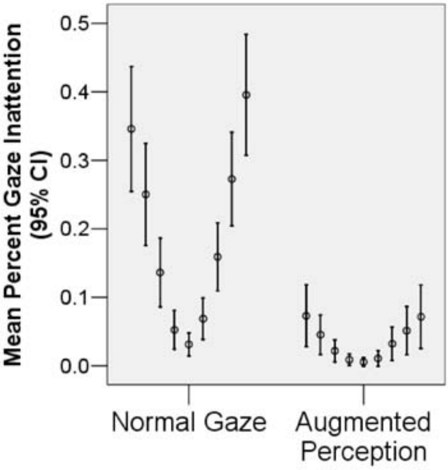

FIGURE 3 Mean percent inattention by the nine seat locations for each condition in Experiment 1 for the participants with and without augmented social perception. Higher numbers on the *y* axis indicate more inattention. CI = confidence interval.

tion and requirement to lecture as between-subjects variables, participant gender as a covariate, and gaze inattention as the dependent variable.

There was a significant main effect of location, $F(1, 35) = 44.69, p < .0001, \eta^2 =$ .53. As one can see in Figure 3, students in the periphery were ignored more than students in the center. There was also a main effect of augmented social perception, $F(1, 36) = 46.22, p < .0001, \eta^2 = .51$, such that teachers with augmented perception ignored students less than teachers without augmented perception. In addition there was an interaction between location and augmented perception, $F(1, 36) =$ 35.90, $p < .0001$, $\eta^2 = .43$; as Figure 3 shows, augmented perception reduced inattention more in the periphery than in the center. Finally, there was an interaction between augmented perception and requirement to lecture, $F(1, 36) = 5.89, p < .02$, $\eta^2 = .07$, such that students were ignored most in the no augmented perception, no lecture condition, most likely due to the extreme boredom resulting from no task or change in visual stimuli.

In this study we demonstrated that alerting participants to shortcomings in their own gaze behavior while teaching virtual students results in a more even distribution of gaze than a simulation without augmented perception. The classroom shape chosen in the current study lent itself to ignoring students in the teacher's periphery. However, when augmenting the rendering of the students to include information about mutual gaze, the teachers ignored students in the periphery much less than teachers without augmented social perception. In other words, the additional social cues increased the ability of the teacher to maintain joint attention through eye gaze (i.e., Clark, 1996) with the students in the classroom. Given that a prerequisite of any substantive communication is to establish common ground (Clark & Brennan, 1991), it is essential to engage students using gaze as a tool to increase their attention (Argyle, 1988) and to increase teachers' ability to monitor all students' degree of attention simply by including those students in their field of view.

Although we demonstrated that the gaze of the teachers changed dramatically in the current study as a function of augmented social perception, we did not attempt to demonstrate that this change in gaze actually would make teachers more effective with real students in a CVE. The goal of the current study was to demonstrate that augmenting a teacher's perception with social information about his or her eye gaze results in better distribution of gaze in a classroom. It could be the case that the specific algorithm we chose to make the virtual students transparent resulted in head movements by the teacher that actually were not conducive toward better learning (e.g., perhaps the movements were excessively fast or jerky). The current study demonstrated that it is possible to change a teacher's nonverbal behavior while he or she is delivering a lecture to a class using TSI in a virtual classroom. By determining optimal nonverbal strategies for various learning scenarios, researchers can provide teachers with the tools to increase their ability to engage students.

EXPERIMENT 2: TRANSFORMED PROXIMITY

Overview

CVEs allow experts to remove many of the physical constraints of social interaction. For example, in the physical world, a presenter can only maintain eye contact with one person at a time, whereas in a CVE, because every audience member sees his or her own rendition of the shared space, it is possible to render separate versions of the presenter, one who appears to maintain eye contact with each audience member at the same time. We call this transformation *augmented gaze*. Eye gaze enhances persuasion (Morton, 1980) and teaching effectiveness (Fry & Smith, 1975; Ottenson & Ottenson, 1979; Sherwood, 1987) and leads to physiological arousal (Wellens, 1987). In a previous study in which a presenter read a persuasive passage to two listeners using augmented gaze, we found that the transformation enhanced agreement and attention (Bailenson, Beall, Loomis, Blascovich, & Turk, 2005; Beall, Bailenson, Loomis, Blascovich, & Rex, 2003).

In Experiment 1, we demonstrated that, in the normal teaching condition without augmented social perception, students on the periphery received less eye gaze from the teacher than students in the center of the room. In this study, we wanted to explore the use of technology and space (see Bielaczyc, 2006, for a review of this concept). Specifically, we explored the idea of changing a student's seat virtually and examined the effect of seat change on learning. In other words, given normal teacher behavior, there may be a *privileged seat*, or a seat that optimally engages the student, in any given classroom. Using TSI it is possible to have two students sitting in one single privileged seat simultaneously (and each of them believing the other student is sitting somewhere else). In the current study, we examined this use of *transformed proximity* by having the same participants learn passages in the center of the room and in the periphery, and then examined the differential learning in each spot.

Design

Participants in this study were students in the exact same virtual classroom as used in Experiment 1. Each sat in one of the learning spots, either right in the center or on either the extreme left or right end (see Figure 4). The shape of the virtual seating arrangement was intentionally created to keep the distance between the teacher and students the same in the two positions while varying only the angle between the front-on position of the teacher and the student. Within subjects, we manipulated seat location; participants sat in either the center or periphery (half of the participants sat in the left periphery seat, and half sat in the right). There were two separate learning passages, one on how the human body fights fevers created by Okita and Schwartz (2006), and one on the pharmaceutical industry. Participants re-

FIGURE 4 A participant's view of the virtual classroom from (left) the periphery and (right) the center.

ceived one passage from the virtual teacher in each seat, and across participants we counterbalanced which seat they sat in first, which passage was received first, and which passage was paired with each seat in a Latin Square design. The volume of the audio from the teacher was kept constant at all seat locations.

Participants

Participants were 32 Stanford University students (16 women) who received $10 for their participation in this study.

Materials

There were two passages delivered verbally by the teacher. The gender of the teacher always matched the gender of the participant, and each of the two passages was recorded in both a male and female voice. Both the fever passage and the pharmaceutical passage were approximately 4 min long, and each had a series of multiple choice questions relating to the verbal content of the passage. The passages as well as the multiple choice questions are listed in the Appendix.

The virtual teacher utilized prerecorded idling movements (i.e., generic "default" behaviors preprogrammed to look realistic) in terms of his or her arms, posture, and head, which were designed to model those of a typical teacher. Furthermore, as the virtual teacher spoke, the lips were synchronized with the volume of the recorded passage. The other eight seats in the classroom were filled with virtual student agents who used the same idling head movements that were collected in the pilot study of Experiment 1. The apparatus and virtual world were identical to those described in Experiment 1.

Procedure

When participants arrived at the laboratory, they were given paper instructions to read based on the experimental condition to which they had been assigned. The instructions indicated that they would be hearing two separate verbal passages by a virtual teacher and would be answering questions about those passages. The experimenter then instructed the participant on how to put on the HMD and use the game pad to answer the questions (see Figure 2). When the participants indicated that they understood the instructions, they put on the HMD and hit a button to begin the first lesson. After the virtual teacher finished delivering the first passage, the teacher and the students disappeared while the participant used the game pad to answer the multiple choice questions about the passage. The questions appeared one at a time. After the participant finished answering questions about the first passage, he or she switched seats in the virtual room, and then the teacher and the students reappeared. The same process then repeated itself with the second passage.

Measures

Learning. We used scores for each of the multiple choice tests after each passage and report scores as percent correct. The mean score of the fever passage was 52% (*SD* = 22%), and the mean of the drug passage was 74% (*SD* = 23%). It is important to note that these scores should not be interpreted in the absolute sense, in that there is no norm for performance given this learning material.

Gaze. We computed the percentage of the total time that the students kept the teacher within their field of view. On average, students kept the teacher within their field of view (i.e., some part of the teacher's head was visible to them) 55% of the time (*SD* = 17%).

Results and Discussion

We ran an ANOVA with learning as the dependent variable; seat (center or periphery) as a within-subjects factor; and order of seat location (center first or second), order of passage (fever first or second), and participant gender as covariates. There was a significant effect of seat location, $F(1, 28) = 4.51, p < .05, \eta^2 = .14$, with students in the center ($M = 68\%, SEM = 4\%$) performing better than students in the periphery ($M = 58\%, SEM = 4\%$). There was also a significant effect of gender, $F(1, 28) = 13.55, p < .001, \eta^2 = .33$, with men ($M = 73\%, SEM = 4\%$) performing better than women ($M = 52\%, SEM = 4\%$). No other main effects or interactions were significant, all Fs < 1.3, all ps > .25.

We next ran an ANOVA with gaze as the dependent variable; seat (center or periphery) as a within-subjects factor; and order of seat (center first or second), order of passage (fever first or second), and participant gender as covariates. The only significant effect was an interaction between seat and order of seat, $F(1, 28) = 4.94$, $p < .03$, $\eta^2 = .15$. As Figure 5 shows (as well as post hoc examinations of 95% confidence intervals of the estimated marginal means), students ignored the teacher most when moved to the periphery seat after sitting in the center compared to the other three cells. None of the other main effects or interactions were significant, all *F*s < 2, all *p*s > .15.

In this study, we demonstrated that students learn better when sitting in front of the teacher than when sitting in the periphery. Furthermore, there was a contrast effect, such that students sitting in the periphery after being first put in the privileged seat looked at the teacher less often than students in all other conditions. The results from this study are similar to our previous work showing the power of teacher gaze in virtual simulations in which we transformed teachers' gaze behavior by redirecting the gaze of a single teacher directly at the eyes of two students simultaneously, thereby demonstrating more social influence for teachers who transform their gazes than teachers who can only look at a single student at one time (Bailenson, Beall, Blascovich, Loomis, & Turk, 2005). In this study, however, we demonstrated that by keeping the teacher's gaze constant, but reconfiguring the spatial geometry of the room, a set of students can learn better if they are all sitting in the center. This strategy of transforming proximity may be more effective than using algorithms to automatically transform and redirect a teacher's gaze because the latter technique involves making head movements and gaze behavior artificial. In contrast, transformed proximity allows a teacher to use natural, realistic head movements but simply increases learning by allowing a number of students to be in the privileged spot to receive those head movements simultaneously.

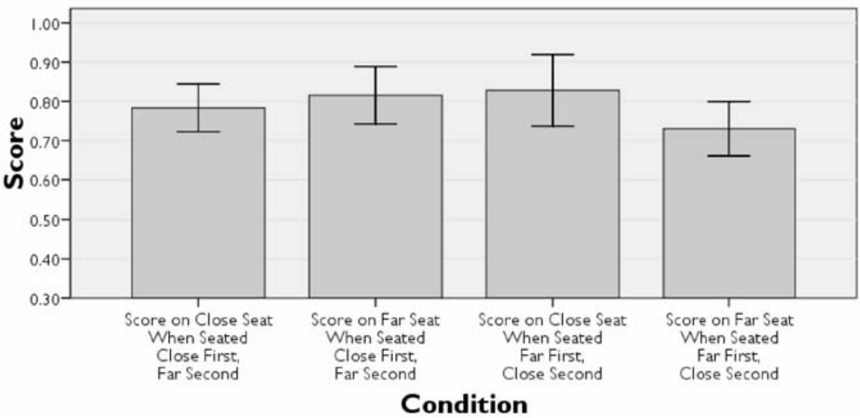

FIGURE 5 Mean gazes and 95% confidence intervals toward the teacher by seat location and seat order in Experiment 2.

We also demonstrated a main effect of gender, such that male scores were approximately 20 points higher than female scores. We did not predict this difference, so our explanation is necessarily ad hoc. This effect may have occurred because, culturally, men tend to have much more experience using video-game-like interfaces (Cassell & Jenkins, 1998; Yee, 2006) and consequently may have felt more comfortable using the IVE system in the experimental setting.

EXPERIMENT 3: TRANSFORMED PROXIMITY—DISTANCE

Overview

In Experiment 3, we sought to replicate the results of increasing learning from transforming spatial proximity via seat location from Experiment 2 by varying the distance between the student and the teacher instead of the visual angle from the front of the teacher. In this study, the angle between the students and the teacher was kept constant while we manipulated the distance between the persons.

Design

Participants performed as students in the virtual classroom depicted in Figure 6. We manipulated two variables in this study. The first, seat location, was manipulated within subjects; participants sat in two different virtual seats close (2.5 m) to the teacher and two different virtual seats far (8.5 m) from the teacher. The 8-min learning passage on pharmaceutical drug companies was broken into four segments. Participants received each learning segment at one of the four seats. Order of seat location, learning passage, and pairings between the two were varied via a Latin Square design. Each of the four learning segments was paired with specific test questions based on the content from that portion of the passage. The second variable, classroom population, was manipulated between subjects; either the other virtual seats were full of virtual students exhibiting the same recorded idling behaviors used in the previous studies, or the classroom was empty except for the participant and the teacher. Figure 6 depicts a bird's-eye view of both conditions.

Participants

Participants were 44 Stanford University students (20 women) who received $10 for their participation in this study.

Procedure

The procedure was very similar to Experiment 2, with the only difference being that the complete 8-min passage on pharmaceutical companies was broken into

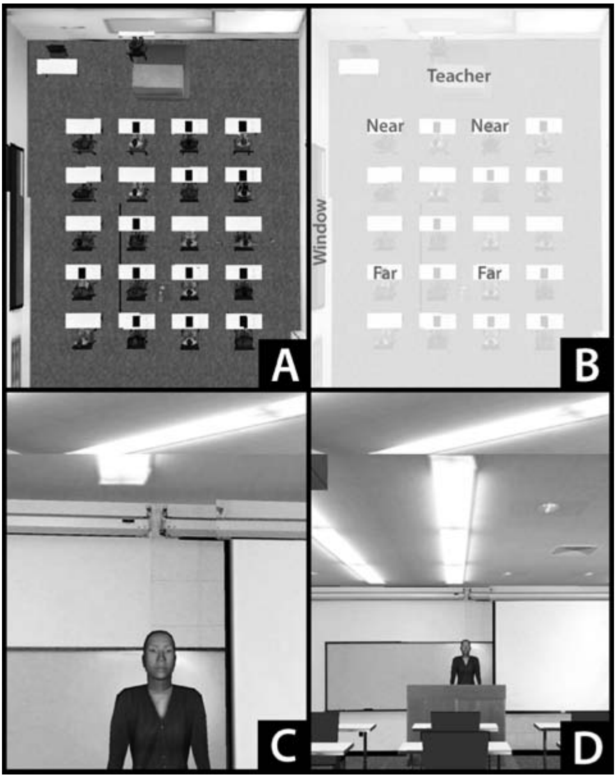

FIGURE 6 Different viewpoints in the virtual classroom: (A) a bird's-eye view of the room layout, (B) the locations of the teacher and participants in the two distance conditions, (C) the participant's viewpoint from the near position, (D) the participant's viewpoint from the far position.

four, 2-min clips, and participants switched among the four seats between clips. Participants answered questions about the passages after hearing all four of the clips.

Materials

The virtual classroom. The virtual setting approximated a standard classroom. Students were arranged in four rows of five seats each (and desks were left unoccupied in the empty condition). The teacher was located at the front of the classroom behind a desk. Behind the teacher was a blackboard. To the right of the blackboard was a screen for projections. A window that showed several red-brick buildings in a campus-like setting was located to the left of the students (see Figure 6).

Measures

The learning score was based on how well participants did on questions designed to test the specific content from the 2-min segments for each seat. We generated four questions for each of the two segments, and we computed a percentage correct for each participant based on his or her results from close seats and results from far seats. The questions are listed in the Appendix. The average learning score was .77 (*SD* = .13).

Results and Discussion

We ran a repeated measures ANOVA with distance (close vs. far) as a within-subjects factor, occupancy of the classroom (full vs. empty) as a between-subjects factor, participant gender and order of seat location (close first vs. far first) as covariates, and lecture score as a dependent variable. There was a main effect of distance, $F(1, 40) = 6.80$, $p = .01$, $\eta^2 = .13$. Participants learned more information from the lecture when they were close to the teacher ($M = .77$, $SE = .04$) than when they were far from the teacher ($M = .74$, $SE = .04$).

There was also a significant interaction between order of seat location and distance, $F(1, 40) = 5.36$, $p = .03$, $\eta^2 = .10$, as illustrated in Figure 7. Again, we observed a contrast effect such that students learned better when sitting close to the teacher (i.e., the privileged seat) after they had sat in the far seat. None of the other interactions were significant, *F*s < .70, *p*s > .45. In sum, although there was a small main effect of distance of about three percentage points, this difference became magnified after students contrasted a seat position with their previous position;

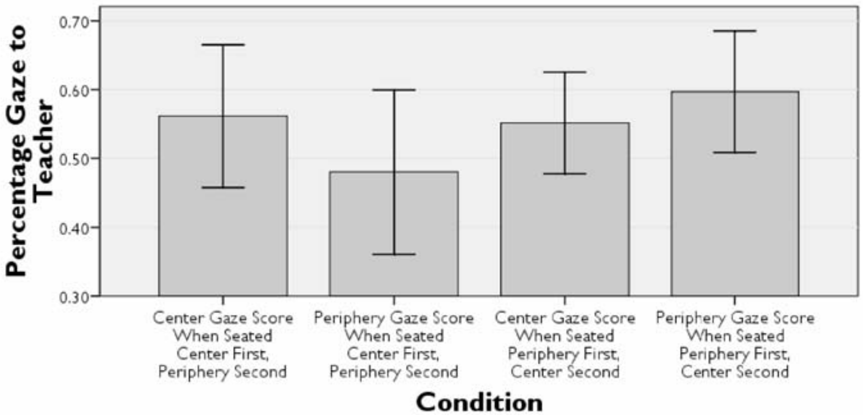

FIGURE 7 Mean test scores and 95% confidence intervals by seat and seat order in Experiment 3.

specifically, performance improved most when they moved from the far seat to the close seat.

The results of both Experiments 2 and 3 were surprising, given that our manipulations occurred within subjects. Conventional wisdom indicates that students tend to select their spot in the classroom; some like the back of the room, some like the front. In the current studies, we demonstrated that, on average, students do learn better in specific privileged seats. The possibilities of transforming proximity during learning via CVEs are not negligible—even with relatively small effect sizes. Considering a class of 100, if each student can occupy the privileged seat, then small shifts in percentages may make considerable differences in terms of the group as a whole.

EXPERIMENT 4: TRANSFORMED CONFORMITY

Overview

Conformity is one of the most powerful aspects of social influence (Asch, 1955; Festinger, 1954). Previous research in CVEs (Blascovich et al., 2002; Swinth & Blascovich, 2002) has demonstrated that participants conform to the behaviors of other people in immersive virtual reality, regardless of whether they are avatars (representations controlled by other people) or agents (representations controlled by the computer). In the current study, we examined the effect of populating a virtual classroom with co-learners (Ju et al., 2005) who exhibited either positive or negative learning behaviors and then examined the change in behaviors by the participants. The goal of the study was to determine if presenters are able to accomplish social influence goals by creating a specific type of audience via transformed conformity.

Design

According to a between-subjects design, participants were randomly assigned to a classroom in one of three conformity conditions: (a) positive, (b) negative, or (c) empty (control). In the positive condition, other agents in the classroom were attentive and focused their gazes on the teacher. In the negative condition, other agents in the classroom appeared distracted and did not pay attention to the teacher. In the control condition, there were no other virtual students. The participants listened to a teacher present a 4-min passage about pharmaceutical companies and then completed a test on the material presented.

Participants

Eighty-two undergraduate students participated in the study for course credit or for pay. Participants were split equally in terms of gender as well as assignment to the three conditions.

Materials

The virtual classroom. The room in this study was identical to the one used in Experiment 3 (depicted in Figure 6). We also added an intermittent distracting event to the setting. Four times over the course of the lecture, cars of different colors, which were visible through the classroom window, drove past outside the classroom. When a car appeared, it was accompanied by the sound of a car engine. In order to see the car, participants had to turn their gazes away from the teacher to see the distracting event (cf. Rizzo et al., 2000).

Virtual co-learner behaviors. In the positive conformity condition, virtual students in the classroom cycled through a set of animations interspersed with periods of neutral idling behavior. This set of animations included (a) looking at the teacher, (b) nodding, (c) taking notes, and (d) not turning their heads toward the distracting event outside the window. In the negative conformity condition, the agents cycled through a different set of animations that included (a) looking at their watches, (b) shaking their heads in disagreement, (c) allowing their gazes to drift around the classroom, and (d) looking outside when the distracting event occurred.

Apparatus. The apparatus used in this experiment was the same as that described for the previous studies.

Procedure

After receiving appropriate experiment descriptions, participants were told by an experimenter that they would be placed in an IVE to listen to an instructor's short presentation in a classroom setting. Participants were also told that they would be answering questions about this presentation later on in this study. The experimenter then showed the participant how to wear the HMD.

After participants adjusted their HMDs for optimum focus and height, the experimenter triggered the start of the study and participants found themselves seated in a classroom as described earlier (always the seat marked with the *X* in Figure 8). The virtual teacher began the prerecorded passage on the pharmaceutical industry, using the same nonverbal behaviors as in the previous studies.

At the end of the passage, participants were taken out of the VE and asked to answer the multiple choice questions on a computer via a Web-based format. Answer choices were selected using the mouse in the form of radio.

Measures

Lecture score. We calculated a learning score based on the number of questions participants answered correctly. Overall, the average accuracy ratio was .70 ($SD = .17$).

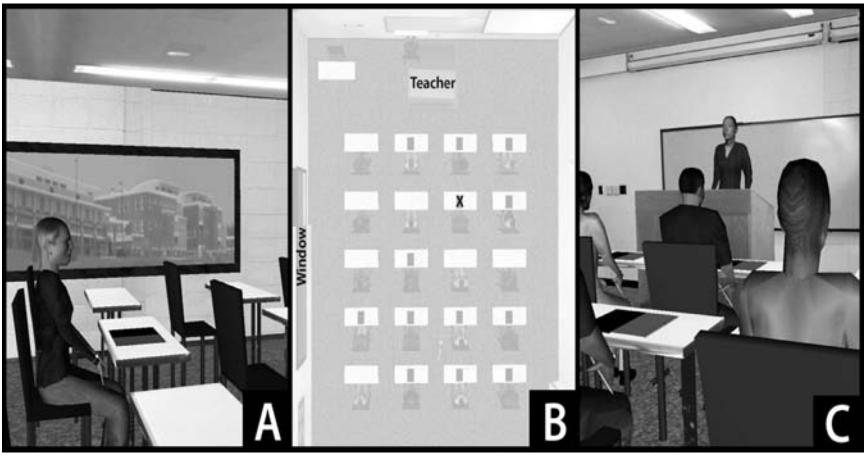

FIGURE 8 (A) The participant's view out the window. (B) A bird's-eye view of the classroom with an *X* denoting the student location. (C) The participant's view of the teacher.

Room score. Participants were also asked about minor details of the virtual setting as a way of ascertaining their spread of attention. There were three multiple choice recognition questions about different aspects of the VE: color of the cars, location of the clock, and how many times cars went by. Overall, the average accuracy ratio was .60 (*SD* = .25).

Gaze. We calculated the percentage of time participants had the teacher agent in their field of view. The mean gaze percentage was .65 (*SD* = .16).

Results and Discussion

We conducted a repeated measures ANOVA with memory type (room details vs. lecture details) as a within-subjects factor, conformity condition as a between-subjects factor, participant gender as a covariate, and learning score as the dependent variable. As Figure 9 illustrates, the interaction between memory type and conformity condition was significant, $F(2, 76) = 3.41$, $p = .04$, $\eta^2 = .09$. A comparison of the 95% confidence intervals revealed that in the empty condition, participants learned significantly more details about the lecture ($M = .74$, $SE = .03$) than they did about the room ($M = .56$, $SE = .07$; $p < .05$); this was also the trend in the positive conformity condition. In the negative conformity condition, the opposite trend was observed: Participants learned more information about the room than they did about the lecture. No other main effects or interactions were significant, all *F*s < 1.5, all *p*s > .25.

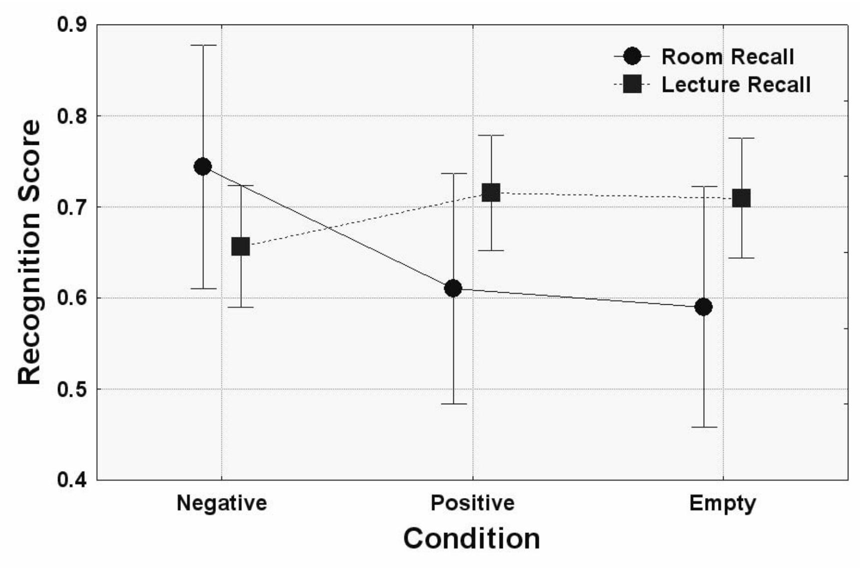

FIGURE 9 Mean learning scores of room and lecture details by condition in Experiment 4.

We next ran an ANOVA with gaze as the dependent variable, conformity condition as a between-subjects factor, and participant gender as a covariate. There were no significant main effects or interactions, all *F*s < 1.5, all *p*s > .25.

In this study, we demonstrated that the behaviors of virtual co-learners change the pattern of learning by participants in the virtual classroom. However, the strongest improvement in memory for lecture material occurred not from populating the room with idealized students, but instead from emptying the room. This suggests that an effective transformation in a CVE scenario may be simply not rendering other students in the room. In other words, by giving every student in a class of 100 the perception that he or she is receiving a one-on-one tutorial by the teacher may lead to the best learning overall as a set. There may be contexts in which having co-learners is essential, for example in collaborative problem-solving tasks or during test taking, when social facilitation effects might occur. However, within the very basic "telling" paradigm of learning examined in the current study, transforming social context to actually remove other learners from the classroom may have been optimal.

GENERAL DISCUSSION

These initial studies demonstrate that using digital transformations of teachers and learners in CVEs can increase learning compared to no transformations in the same environments. In Experiment 1, we demonstrated that teachers are better able to spread their gazes among students when receiving real-time visual feedback about which students they have been ignoring. In Experiments 2 and 3, we demonstrated that transforming the spatial configuration of a virtual classroom changes how much students learn. Specifically, sitting in the center of the teacher's field of view results in more learning than sitting in the periphery, and sitting in the front of the room results in more learning than sitting in the back. Moreover, in both of these studies we observed contrast effects, such that the transition from the privileged seat to the worse seat is particularly detrimental for learning and attention. Finally, in Experiment 4, we demonstrated that transforming the social behaviors of virtual co-learners results in differential learning; emptying the room of other students results in the most learning of course materials and the least learning of non-course-related details compared to other transformations of co-learners.

In general, we believe there are two important advances based on the current work. First, we demonstrated that in VEs, social behaviors such as head movements, spatial proximity, and the presence of virtual others all have an impact on learning. Given that the lecture material delivered by the virtual teacher was completely unrelated to any of the nonverbal social behaviors manipulated, it is notable that the relationship between the social cues and learning was so strong, sometimes more than 10 percentage points. A compelling argument can be made that social information during a lecture helps most when it is meaningfully linked to the information delivered in the lecture (e.g., using hand movements to approximate shapes, or using facial expressions to accent negative or positive statements). In the current work, we demonstrated that even when the information delivered by the virtual teacher is completely unrelated to the transformed social behaviors, learning improves simply by designing social cues to optimally engage students. Previous researchers have pointed out that it is crucial to attend to the social affordances of digital environments by leveraging the ability to monitor social cues (Kreijns, Kirschner, & Jochems, 2002). The current data demonstrate how critical those affordances can be. Moreover, the current findings provide support for the notions that in physical, face-to-face instruction contexts, the seating arrangement and level of eye contact between teacher and student may be extremely important.

Second, we demonstrated that digital transformations of learning environments (i.e., Pea, in press) can result in more learning. By having multiple students sit in a privileged virtual seat simultaneously, optimizing behaviors or physical presence of co-learners, or by augmenting perceptions, student nonverbal behaviors, attention, and learning can be altered. Consequently, the possibility for teachers to augment themselves with digital transformations deserves consideration, especially in larger groups in which tailored social cues from a physical teacher are not possible.

There are a number of limitations to the current study. First, here, we did not implement the constructivist learning tasks that learning science as a field deems the most worthwhile. Although testing memory for verbal content was a logical place to begin for CVEs due to the ease of implementing the materials in that manner, we agree that this one learning component in no way approximates the entire holistic learning process. In future studies, we plan to test various combinations of learning components—mixing physical and digital environments as well as passive and active learning processes—in order to slowly isolate the optimal pattern of learning components that exist in a world that includes learning via digital media. Similarly, we need to test the various components by examining different types of learning content; different types of nonverbal gestures and social behaviors; and different types of social contexts, ranging from the formality of the learning environment (Bransford et al., in press) to the physical shape configuration and size (Sharon, 2003) of the virtual classrooms. The utility of our various learning components may vary drastically as a function of these larger contexts. Also, our studies did not take into account students' natural preferences for seating locations. An intriguing question is whether students who naturally prefer the less optimal locations would learn more or less when forced to be in the more optimal locations. It is also important to point out that our studies relied on short-term, single-trial tasks and that different patterns quickly emerge over time. Finally, given the novelty of using IVEs, the findings from the current studies may not generalize to learning environments that are not so reliant on extravagant technology. A thorough examination of the theoretical constructs examined in the current work using technology that is more accessible for classrooms is essential. Moreover, the small and unrepresentative sample size of the current study should be addressed in future work before generalizations are made.

The potential for future work examining the effects of TSI in CVEs is striking. The possibility of both teachers and students to transform their appearance and behaviors, their perceptual abilities, and the social context of a classroom present promising opportunities. In previous work we demonstrated that, in CVEs, one person can automatically and implicitly mimic the nonverbal behaviors of others (Bailenson & Yee, 2005), and by doing so can capture the attention of an audience and become more persuasive. In a virtual learning scenario, a teacher who differentially mimics each student in a class of 100 simultaneously should be extraordinarily effective. The ability to filter in real time, appearance, behaviors, contexts, and even the fundamental aspects (i.e., race, gender, etc.) of peoples' identity should provide learning scientists with tools that were difficult to imagine decades ago (Loomis, Blascovich, & Beall, 1999).

Of course, one must consider the ethics and morality of such a research paradigm. It is a fine line between strategic transformations and outright deception. In face-to-face scenarios, teachers must often mask their emotions; for example, smiling at students when they are in fact extremely upset or praising students who deliver less-than-stellar responses. TSI is not qualitatively different from putting a mask over the true expressed emotional state of the teacher. However, the quantitative deviation from physical reality via TSI does provide a substantial quantitative difference from putting on a smile or nodding encouragingly.

In previous work we examined the ability of people to detect TSI in digital interactions, ranging from the exchange of simple digital photographs (Bailenson, Garland, Iyengar, & Yee, 2006) to more elaborate CVE contexts (see Bailenson, 2006, for a review). Over dozens of studies, a similar result occurred: People are very poor at detecting transformations of appearance and behaviors during the exchange of digital information. Consequently, the possibility for abuse in these manipulations is real, and learning scientists should openly discuss the pros and cons of engaging in such a research paradigm.

In sum, the practical implications of the current work are clear: Digital transformations through media can increase students' learning in some contexts. Of course, students across the world are not all going to don HMDs anytime in the near future; however, the possibilities of using other types of digital media—video games, Web pages, and others—are growing. The theoretical findings from the current article should extend to any digital media in which avatars interact in learning contexts.

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APPENDIX

Pharmaceutical and fever passages with corresponding multiple choice questions. Answers are italicized.

Pharmaceutical Passage

I'm going to be talking to you about something that I think almost all Americans are concerned about these days: the pharmaceutical industry and, in particular, the high prices it charges and the justifications it gives for charging those high prices. This year Americans will spend about $250 billion on prescription drugs, making them the fastest-growing component of our health care bill, which itself is growing very rapidly. The skyrocketing expenditures on prescription drugs are partly a matter of greater overall use —more people are taking more drugs—but it's mainly a matter of increasing prices. New drugs are almost always priced higher than old ones, and once on the market, for the drugs that are most commonly used, the prices are jacked up, usually at about three times the inflation rate, so it's unsustainable. Most Americans have insurance that covers at least part of drug costs, but not everyone. Medicare, for example, does not have a prescription drug benefit yet (and I'll say more about that benefit later) so that Medicare recipients who do not have supplementary insurance have to pay for their prescription drugs out of pocket. And, in one of its more perverse practices, the pharmaceutical industry charges much more for people who don't have insurance than they do for people who have large insurance companies to bargain for lower prices or rebates. In 2002, senior citizens paid, on average, $1,500 per year for the drugs that they took, and if they took six drugs, which is not rare for an older person, they had a bill of $9,000 a year. Not many senior citizens have such deep pockets. In fact, a recent survey showed that one-third of senior citizens either did not get their prescriptions filled in the first place, or if they did get them filled, didn't take the full dose but played out the dose to make the drugs last longer. In recent years there has begun to be a public outcry about this, probably stimulated in large part by the knowledge that you can buy exactly the same drugs in Canada for about half the price. This has caused people to look very carefully at the pharmaceutical industry. Still, the industry has been remarkably successful in dampening any serious move toward price regulation. Witness, for example, the Medicare prescription drug benefit that Congress passed late last year; it will go into effect in 2006. That bill actually contains a provision that explicitly prohibits Medicare from using its bulk purchasing power to bargain for lower prices with drug companies. That's quite a provision. It makes, first of all, prescription drugs unique in the Medicare system. Medicare does regulate doctors' fees, Medicare does regulate hospital payments—but prescription drugs are off the table. Drug companies can continue to charge whatever the traffic will bear, and it will bear quite a lot. How does the pharmaceutical industry justify its high prices? What it says, what it would like you to believe, is that the high prices are necessary to cover their high research and development costs, which implies that they spend most of their money on research and development and that afterwards they have very little left over—enough for modest profits but not much more than that; they're just getting by. They also make the argument that they are a highly innovative industry and they need the high prices as a spiritual incentive for their innovation. They say that any form of price regulation would choke off the stream of miracle drugs that they are turning out, so don't mess with us. A part of this argument is the implication that this is somehow a peculiarly American industry, that the pharmaceutical industry is an example of the success of our free enterprise system. Other countries have drug price regulation; we don't, and therefore this industry is an American industry that is especially innovative and successful because there is no price regulation. That's implied—it's not stated exactly, but it's implied. What they are saying with these arguments is, You get your money's worth. Just shut up. Pay up. You get your money's worth—is that true? Do you get your money's worth? The reality of this industry is very different from the image it tries to portray in its public relations. There is a huge rhetoric reality gap.

1) According to the speaker, increases in prescription drug spending are primarily based on increases in:

people taking drugs
drugs available
drug prices
the aging population

2) According to the speaker, prices charged by the pharmaceutical industry vary.

People without health insurance pay less for drugs than people with insurance.
Insurance companies pay more for drugs than individuals without health insurance.
The pharmaceutical industry charges people without insurance more for drugs.
People without health insurance bargain for lower prices or rebates.

3) According to a survey cited by the speaker, one-third of senior citizens:

do not get their prescriptions filled or take less than a full dose to make the drugs last longer
take six drugs which can cost up to $9000 per year
buy their drugs from Canada in order to pay lower prices
rely on Medicare to subsidize their drug purchases

4) According to the speaker, buying drugs in Canada:

is illegal
substantially decreases the incentive of US pharmaceutical companies
can cut costs of the drug by half
is encouraged by a bill passed in Congress

5) According to the speaker, the Medicare prescription drug benefit:

encourages Medicare to bargain for lower drug prices
prevents Medicare from using its bulk purchasing power
prevents low income seniors from spending over $300 a month on drugs
encourages drug companies to lower prices for Medicare recipients

6) According to the speaker, the pharmaceutical industry claims that high prices for drugs are necessary in order:

to enable the effective marketing of new innovative drugs
to compensate shareholders for their investments
to pay the pensions of an increasing number of retired workers
to cover high research and development costs

7) According to the speaker, the American pharmaceutical industry claims that it is especially innovative and successful

because it employs graduates from America's best research universities
because prices are not regulated by the government
because of superior technology
because of a collaborative mentality

8) According to the speaker, the profit history of pharmaceutical companies demonstrates that the risk of this industry is:

higher than other industries in the US
comparable to other industries in the US
lower than other industries in the US
highly variable and hard to compare with other industries

Fever Passage

Many people worry when they get a fever. But, a fever can be a good thing. It means the immune system is working to kill an infection. A fever means the body is hot, and the heat helps to kill *pathogens*. Pathogens include things like bacteria and viruses. The brain has a region called the *hypothalamus*. The nerve cells inside the hypothalamus create a *set point* that determines how hot the body gets. When the set point rises, it causes the body to get hotter. The set point rises when pathogens invade the body. The way this works is that a person's immune system can detect when there are unusual organisms in the blood. The immune system releases *macrophages* that attack the pathogens. The macrophages are cells that float in the blood. Macrophages also produce a chemical called, *IL-1*. When IL-1 reaches the hypothalamus, it causes the set point to rise. IL-1 tells the hypothalamus that the body is in a state of emergency, and that the temperature must be raised a few degrees to kill the pathogens. This causes the body to run a fever. What processes cause the body to increase its temperature? One process involves *vascularization* near the skin. Vascularization means the veins (blood vessels) shrink. When veins shrink it means that less blood can get near the skin, and therefore, the blood cannot release as much heat through the skin. Vascularization helps explain why people can have a fever but still feel cold in their hands and feet. There is less blood near the skin. A second process involves shivering. Shivering makes the muscles move. When muscles move, they produce heat. Shivering can make the body produce more heat than normal. A third process is *piloerection*. Pilo means hair, and erection means stand up right. Piloerection causes the small hairs on the body to stand up. Piloerection closes the pores in the skin and makes the hairs stand up. This means less heat can escape through the pores. It also means that less sweat can escape through the skin. This is important because sweating is a cooling mechanism and fever is the body's way of increasing the temperature, not decreasing it. Piloerection also helps explain why a fever causes a person's skin to feel tender. The little hairs get rubbed and irritate the skin. The hypothalamus also releases a chemical called the *thyrotropin releasing hormone* (TRH). TRH, in turn, causes the release of another chemical called the *thyroid stimulating hormone* (TSH). TSH increases the metabolism of various tissues in the body. A higher metabolism means that tissues use up energy faster, and this causes them to produce more heat. The higher metabolism helps to explain why people have rapid breathing and a rapid heart rate when they have a fever. The tissues with an increased metabolism need more blood and oxygen than usual. If the body gets too hot, it will begin to kill its own cells. How does the body stop from getting too hot? When the body temperature reaches the set point in the hypothalamus, all the processes reverse. Blood goes to the skin, shivering stops, piloerection ends, and the hypothalamus stops the production of TRH. Aspirin and Tylenol help reduce a fever by blocking IL-1 from reaching the hypothalamus. This helps to bring down the set point, so the body stops trying to heat up. The good part of aspirin is that it makes one feel better. The bad part is that there is less fever to help kill the pathogens.

1) According to the passage, your hands and feet get cold when you have a fever because

your veins shrink
there is more blood near your skin
of the effects of IL-1
the small hairs on your body stand up
none of the above

2) Which of the following is *not* a process that causes the body to increase its temperature?

piloconstriction
vascularization
macrophage-activation
shivering
both a and c

3) What does Aspirin/Tylenol do?

increase a fever
block IL-1 from reaching the hypothalamus
increase the set point so the body stops trying to heat up
reduce vascularization
both b and d

4) When you have a fever …

your body's cooling mechanism shuts down
heat production kicks in
your skin feels tender
all of the above
none of the above

5) According to the passage, how is the brain involved with a fever?

The hypothalamus produces IL-1
The brain releases macrophages
The brain attacks the pathogens
The hypothalamic nerve cells create a set point
Both a and b

6) What is the relation between TRH and the TSH?

TRH causes the secretion of TSH
TSH causes the secretion of TRH
TRH blocks the effect of TSH
TSH blocks the effect of TRH
None of the above

7) Which of the following is a way that the body stops from getting too hot?

Muscles controlling hair follicles contract to use up energy
Shivering begins to use up heat
Blood goes to the skin
Macrophages block IL-1 signaling
Both c and d

8) Birds do not have hair and they do not sweat. But, piloerection also helps them have a fever. How?

Piloerection creates heat by activating hair follicle muscles.
Piloerection traps body heat.
Piloerection signals the hypothalamus to increase the set point.
Piloerection causes tender skin, which makes fevers more likely.
Both a and b

9) Imagine that there are no pathogens in your body and your body temperature is normal. What will happen if you take an aspirin?

Your body temperature will increase in anticipation for a fever.
Your body temperature will stay the same.
Your body temperature will decrease.

Your body temperature will increase, and then decrease.
Your body temperature will decrease, and then increase.

10) Here is a common situation: People wake up all sweaty and they are finally cured from their flu. Does the sweating help them to cure their flu?

Yes, it helps rid the body of pathogens.
Yes, it increases the effect of vascularization.
No, it is a by-product of the body's increase in temperature.
No, it is a direct effect of TRH.
It cannot be determined.