Collaboration and Learning within Immersive Virtual Reality

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ABSTRACT

We are studying collaboration and learning within immersive virtual reality (IVR) using a head-mounted display technology. This research, supported by the College of Education and Human Interface Technology Laboratory at the University of Washington, is currently concerned with the activities of 56 ninth grade students at work in a public school environment. Subjects worked as individuals and in pairs while investigating the concepts of global warming within an audio-enhanced virtual reality model of Seattle called Global Change World (GCW). Three groupings of subjects were provided with different collaborative experiences while immersed within the GCW virtual learning environment: (1) Individuals who received minimal support during the learning exercise provided; (2) Paired peers who collaborated throughout the learning exercise; and (3) Individuals who completed the learning exercise in collaboration with an in-world expert companion. It is concluded that collaborative IVR learning experiences can be successfully integrated into existing school curricula in spite of a significant lack of knowledge regarding the nature of human communication, interaction, and learning within VLEs.

Keywords

Collaboration, Conceptual Change, Multi-User Virtual Learning Environments, Immersive Virtual Reality.

1. INTRODUCTION

The use of virtual reality (VR) in education has in recent years become more commonplace. For example, Youngblut [30] identifies fifty-five examples of VR applications that are specifically designed to support learning. In the past, most educational applications of VR have involved a single student interacting with objects within a virtual learning environment (VLE). Advances in VR technologies, however, are opening the doors to a broad investigation of the potential for collaborative, multi-user VLEs designed to enhance educational experiences. As it becomes possible to easily place more than one student within a VLE simultaneously, questions arise regarding the potential impact of the collaborative aspects of the experience on learning processes.

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Currently, very little is known about collaborative learning processes using VLEs [30]. Over the coming years, however, everyday educational practices can be expected to rely increasingly upon collaboration and interaction within these kinds of learning environments [17]. Collaborative learning exercises are valuable because they help students clarify ideas and concepts through processes of articulation and discussion [26]. In requiring that learners invest significant mental effort, collaboration supports active learning and deep processing of information [2]. Newman, Johnson, Webb, & Cochran [21] compared face-to-face collaborative activities with computer supported collaboration and concluded that face-to-face interaction was better for creative problem exploration and idea generation while computer-based conferencing was better for linking ideas, interpretation, and problem integration. It is conceivable that the virtual face-to-face nature of VLEs may provide unique collaborative experiences that draw upon the best attributes of both face-to-face and computer-based collaboration.

Figure 1. Observing students interacting while in GCW

This paper describes a study designed to provide simultaneous multi-user interaction within a VLE called Global Change World (GCW). GCW is a fully immersive, multi-participant VLE designed to investigate the dynamics of collaboration in the domain of science education. Investigations involving GCW are conducted through the Learning Center at the Human Interface Technology Laboratory (HITL) on the campus of the University of Washington in Seattle and are funded by a grant from the UW Royalty Research Fund. Though GCW was implemented in this study as an in school, single location, multi-participant learning experience, it has also been run and tested over the Internet with some success.

Using networked Hewlett-Packard workstations running DVISE software, GCW provides a unique collaborative experience by employing head mounted display helmets (HMDs) that have been fitted with an intercom system to allow for voice communication. The immersive visual display, combined with voice communication capabilities, enables both students and instructors to easily talk to each other, seemingly from within the three-dimensional environment of GCW. We found this system to be highly appropriate for supporting peer collaboration and it appears to be capable of promoting very high levels of presence within the VLE.

We first provide background information outlining the reasoning behind the development of collaborative VR experiences for educational purposes. The next section describes the features and functioning of the GCW environment. The paper concludes with a description of the GCW study design and a discussion of findings assembled to date in the ongoing analysis of data collected during the study.

2. BACKGROUND

The use of virtual environments (VEs) as an alternative form of data representation has become an increasingly attractive option for computer interface designers across a variety of disciplines, including education. It is considered an alternative approach because in a VE the user is no longer looking at data on a screen but they are immersed as active participants within the data itself. The VE can be realistic, as would be the case with models of building interiors that users walk through and explore, or abstract, such as a theoretical 3-D representation of molecules and their associated molecular forces [16]. For VE designers the goal is for the interface to be as transparent as possible and that it make intuitive sense to prospective users [1]. The interface should allow for direct manipulation of objects in the VE using hands, body movement, or through virtual tools that allow participants to observe and interact within the VE as naturally as they would interact with objects in the real world. Such design approaches cause the interface, in effect, to disappear.

Discovering the best ways to employ VR in support of teaching and learning abstract concepts continues to be a challenging and elusive goal for researchers. In general, the potential for VR to benefit education is widely recognized and a number of studies have conclusively demonstrated the ability to teach content using VR under certain prescribed conditions [5, 8, 19, 23, 29,30]. A significant challenge remains, however, in fusing specific affordances of VLEs with educational methods capable of exploiting them into demonstrable theories of learning for VR.

Zeltzer [31] refers to the three attributes of autonomy, presence, and interaction in describing the affordances VR provides. Autonomy refers to the notion that a VE is to some extent capable of performing its own actions, independent of user intervention. An autonomous VE follows its own path to goals and may or may not change its course in response to user actions. Presence is simply the experience the user has of being in an actual place when immersed within a VE. Zeltzer claims that for presence to be high, the user must be allowed to interact with the VE both naturally and intuitively. When presence is high the computer interface disappears. Finally, interaction involves the ability of the user to perform actions in the VE according to a logical rationale. Even though the user may have to learn how to function appropriately within the environment, the laws that govern the VE should become apparent over time, allowing for a meaningful interactive experience.

Most educational applications for VR are designed to make use of these and other unique features and affordances. Other affordances include: (1) Allowing students to gain a greater understanding of abstract concepts through the creation of visual metaphors; (2) Allowing students to directly manipulate and scale virtual objects or environments for clearer understandings; and (3) Allowing students to visit places and interact with events that distance, time, or safety concerns would normally prohibit [28, 30]. Designers of VLEs tend to believe that students retain, master and generalize new knowledge better when given the opportunity to become actively involved in constructing that knowledge through a coherent, firsthand interaction with knowledge domain representations.

Much of the appeal for applying VR in education is derived from the observations of educational theorists like Bruner [3] and Piaget [24] who have long stressed the value of actualizing learning through making it more real for students. VR technology allows for the creation of VLEs where students can learn by interacting with virtual objects similar to the ways they would interact with real objects. Through immersion in a VE, students become a part of the phenomena that surround them. Learning is facilitated through the construction of concepts built from the intuitions that arise out of their direct experience of the environment. More recently, research [1, 6] has supported the notion that VLEs, by their very nature, increase the human capacity for certain types of learning by allowing users to cross the boundary between third and first person experience, negating the need for a highly abstract symbol system. In traditional education, learning the symbol system of a particular knowledge domain is often a prerequisite to learning its content, as in the case of mathematics or music [28]. The problem with this type of learning is that mastery of the symbol system can often be mistaken for mastery of the content, and teaching may end well before students make the link between the two.

First person, or direct, interaction within a VE allows students to construct knowledge out of their own experience without relying on symbol systems. This concept of knowledge construction among learners is more generally referred to as constructivism [10]. Self-constructed knowledge is highly individualized and may represent an improvement over similar knowledge learned by other methods because the learners shape the learning experience themselves. In other words, instead of relying on third-person instructor or text-based accounts of how things occur in the world, students immersed within VLEs can directly experience and interact with the concepts, principles, rules, and procedures found in the domain. VLEs designed from the constructivist approach are seen by some as having great potential for providing powerful learning experiences [1].

Constructivism has entertained a long history in education and philosophy and is representative of a wide diversity of views that may be summed up in the following points: (1) Learning is an active process of constructing rather than acquiring knowledge; and (2) Instruction is a process of supporting that construction rather than communicating knowledge [11]. While constructivism is seen to imply that there is a tangible world, it argues that it is individuals who impose meaning on that world. Consequently, there can be many meanings or perspectives for any event or concept and the goal of education can no longer be one of instilling an absolute, correct meaning [10]. More importantly, constructivism brings with it the underlying assumption of a learner-centered approach to instruction.

Constructivist arguments are often used to defend the design and implementation of VLEs.

Traditionally, most VLEs have placed a single student within the VE. However, as the technology becomes available educators are becoming interested in investigating the potential for collaborative learning in VEs. There has been considerable research on the value of collaborative learning. O'Malley [22] found that much of the research on collaborative learning has evolved from the works of Piaget [25] and Vygotsky [27]. Crook [7], for example, views peer collaboration as having three basic cognitive benefits; articulation, conflict, and co-construction. According to Crook, peer collaboration forces students to make their ideas explicit and public. To do so, they need to learn to clearly articulate their opinions, predictions, and interpretations. Conflict may arise when students disagree in regards to their interpretations. To resolve the conflict engendered by collaboration, they must justify and defend their positions and are thus forced into reflection. Piaget [25] offered a similar view, noting that socio-cognitive conflict often arises when students holding inadequate or differing views work collaboratively. As these differing views are sorted out, students are forced to reflect upon their own conceptions. Crook's concept of co-construction is based upon Vygotsky's [27] belief that learning is the sharing of meaning in a social context. Students collaboratively co-construct shared knowledge and understanding by building upon each other's ideas. Given the ability of VLEs to support multi-participant activities, it is easy to see why educators are very interested in examining the potential for using them to support collaborative learning.

Beyond these general issues regarding the use of VR in education lie domain specific questions concerning the learning content to be embedded within VLEs. In the domain of science education, for example, where a lack of understanding regarding how and why students construct and change their scientific worldviews has long posed fundamental problems for science educators, of what practical use are VLE experiences? This question is of particular concern for the science-based learning environment of GCW, and the answer is both intriguing and complex. For example, as VLE researchers one of our greatest challenges is to develop ways of using VLEs that assist students in overcoming the learning problems that complicate the understanding of scientific phenomena without providing the opportunity for students to create new and completely unintended misconceptions [29].

In science education, teachers have traditionally struggled to find ways to spark lasting conceptual change within their students [4]. The notion of conceptual change is commonly understood to refer to the development of scientific conceptions from naïve ones. A common strategy for supporting conceptual change lies in the creation of contradiction-induced changes in students' perceptions of phenomena that eventually result in learning [12]. However, science educators have difficulty in achieving this because students typically come to class lacking essential conceptions and, more importantly, also hold a wide variety of misconceptions regarding scientific phenomena. It is commonly observed that students are extremely reluctant to let established misconceptions go, even in the face of compelling evidence [9, 12, 20].

VLE research using GCW in the science classroom seeks, in part, to provide new insights into age-old science education problems. In light of what is known about the complex nature of both the science learner and science education, there is good reason to believe that VLEs can play a strong role in supporting science-learning activities. They can do so by directly addressing known barriers to the conceptual change process. In GCW learning is not based upon the memorization of facts and formulas but seeks to draw upon students' everyday life experiences and knowledge as they seek solutions to what is presented as a real-world problem. For example, students access a virtual thermometer and actually measure the air temperature of a simulated physical space. The learning experience of GCW is designed to encourage natural and intuitive interaction and can be structured to provide the experiences that guide students from the naïve notions of their everyday thinking towards scientific thinking.

This research theorizes that VLEs can be designed to address the problem of strongly held scientific misconceptions by allowing students to discover scientific principles both constructively and collaboratively. On their own in the VLE, it is anticipated that students will attempt to make personal sense of what they are experiencing through direct interaction with the environment. This is a constructivist view of learning and is seen as providing a valuable means for having students construct a relevant and personalized knowledge base through working with and using their own ideas [10]. VLEs are seen as being useful in constructivist learning applications, particularly when developed to support science-based learning activities [30]. Through interaction within a constructivist VLE, the process of conceptual change is scaffolded as it provides a very personalized means for students to become dissatisfied with their initial science conceptions. As they observe the results of their actions it is expected that they will more easily move to new conceptions on the basis of plausible, intelligible, and fruitful personal manipulations of their surroundings. This study comprises an experiment that attempts to demonstrate this potential.

Collaboration is considered a critical component of the study since learning is often described in terms of being largely social in nature [2, 27]. The social aspects of learning must be considered when examining conceptual change because through collaboration learners will encounter challenges to their thinking that extend beyond the bounds of their own internal conflicts. Conceptual change is facilitated through the personal reflection demands of the articulation of ideas and the resulting social co-construction of new concepts [7]. Within collaborative, science-based VLEs, it is hoped that students will be guided closer to accurate scientific thinking through both internal and external negotiation. In collaborative exercises students are encouraged to interact with and internalize modes of knowing and thinking that have been created by a community and are thereby provided the opportunity to consider other participants' expertise in drawing their own conclusions.

The GCW research project is guided by the notion that by engaging students in the collaborative, constructivist, immersive, and interactive activities of VLEs, conceptual change may be facilitated by confronting three of the key barriers to effective science learning: (1) Students perceive the learning of science as the memorization of facts and formulas, not as developing skills for investigating problems on their own; (2) Students rarely see a relationship between the science they learn in school and the science problems they are able to actually encounter in everyday life-like situations; and (3) Students gain inaccurate representations of scientific understandings because science learning in school is almost entirely individual and non-social, completely ignoring one of the primary intrinsic motivations available to teachers in getting students excited about science, namely peer interaction [4].

The potential for VLEs to support educational activities has been both speculated upon and demonstrated for a number of years now. The research issue, though, cannot be merely one of demonstrating that VLEs are effective as an educational technology. The real challenge for researchers of VLEs is to demonstrate that they can produce learning outcomes that are different, if not better, than outcomes achieved by other means. If this can be demonstrated, then we will be well on the way towards understanding how VLEs can be used to enhance a variety of educational experiences. The key to reaching this goal will be found in applications that: (1) Make good use of the specific affordances of VR; and (2) Rely on proven instructional design practices, such as collaborative activities, developed specifically for VLEs.

3. GLOBAL CHANGE WORLD

GCW was designed and programmed by the Learning Center of the HITL at the University of Washington, Seattle. The GCW environment is created by two networked Hewlett-Packard 9000 workstations running DVISE VR software. Hardware manufactured by Division Corporation provides the physical user-interface and consists of an audio/visual rendering system connected to a HMD helmet, navigation and control wand, and a position tracking system. In addition, microphones and speakers in the HMDs are used to allow students to speak to each other while within the world. This enables easy communication between partners on a personal level and has been found to be beneficial in supporting collaboration and enhancing feelings of presence in the VLE [15].

GCW is capable of facilitating within-world collaboration by allowing more than one subject to be fully immersed and interactive within a common VE at the same time. Currently, GCW can support two subjects in the world at the same time. By using helmets that present exclusive, fully immersive stereo graphics, a wand that allows navigation and other manipulations within the VE, and a within-world audio communications system, subjects are encouraged to interact with each other and the designed components of the VLE. Preliminary school visits [15] with GCW using the standard Division hardware setup did not provide an audio communications system. Students had to call to each other across the room and instructors had to guide activities in the virtual world by speaking to them from a real-world vantage point. While this approach did have positive results, the Division equipment was not ready-made to support communal activity.

To better support collaboration, an intercom system was installed in the helmets that allowed the voices of both students and instructors to appear to come from within the VLE. This innovation enhanced communication and improved our ability to instruct students on how to interact with GCW. Students were now able to easily question each other about their whereabouts or activities in the VLE. As we watched what they were doing on a video monitor we could make suggestions to them either individually or as a pair through a microphone plugged into the audio mixer of the intercom system. This approach was very effective, as indicated by the observation that students would often look around the VE and ask where we were when they first heard an instructor's voice. In addition, when going into the world as a guide for the student we could talk directly with them while demonstrating how to interact in the world. This capability has helped students learn how to function in the VLE faster [14].

The designed environment of GCW comprises a selectively realistic representation of the city of Seattle, Washington, which is not intended to be a direct or accurate model of all components of the real Seattle environment. The virtual model was initially constructed from a topographical map of Seattle and is representative of a 6x4 mile plot centered on the downtown area. The Space Needle is one the few features of the real city, other than the general topography, that has been included in the virtual city. Selective realism for VLEs implies that only elements necessary to the goals of the learning exercise will be provided in the virtual model. In most cases, precisely duplicating all features of a real environment would be computationally prohibitive. In attempting to model real environments many aspects of them may be omitted or altered, such as social and economic dynamics. For example, in GCW complex processes and their outcomes are condensed into and metaphorically represented as three large wheels that subjects manipulate to alter environmental variables and outcomes.

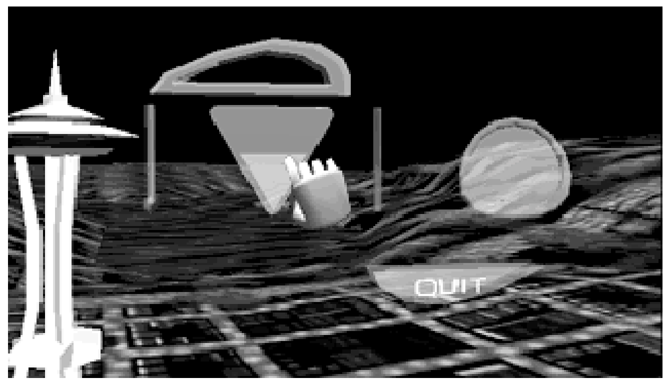

Figure 2. Selecting the gas-gauge of the GCW toolkit

The basic features of GCW, shown in Figure 2, allow subjects to experience a sense of being in a completely different place via the aforementioned phenomenon of presence. While this place may be somewhat similar to a world familiar to them, the Seattle area for example, in GCW the experience of this familiar world is extra-sensory in that the environment allows them to: (1) Interact with and alter environmental variables on a global scale; and (2) Travel through time to see the results. These unique affordances of VR, and GCW, are expected to supply learners with experiential metaphors and analogies that will aid in understanding the complex phenomena of global climate change processes. In its best application, a VLE will allow students to experience and do things that are not possible by any other means. The provision of extra-sensory features in GCW, in conjunction with collaboration, is expected to help students displace intuitive misconceptions about global warming phenomena with alternative, more accurate mental models.

Students enter the virtual model of Seattle in the year 1997; significant only because this was the year GCW was initially programmed. They are able to navigate their way around the world using control buttons on the wand while viewing the world through the stereoscopic HMD. Virtual representations of each participant, known as Avatars, appear as cartoonish pairs of large eyes, spiral ears, a triangular-shaped mouth, and a singular cyber hand with which they can manipulate objects. This is a very simple representation yet students have no problem whatsoever meeting and conversing with their companion's Avatar [14]. Conversations between students and with instructors take place via the intercom system built into the HMD.

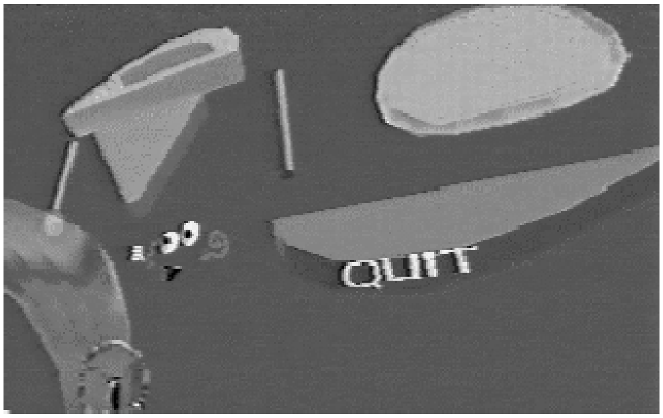

Figure 3. An Avatar looks at the toolkit of GCW

In order to perform tasks within GCW, students access a virtual tool kit that allows them to measure the average air temperature for the current year, the parts per million of greenhouse gasses currently in the atmosphere, the annual rainfall for the current year, and access a time travel portal. In addition, the temperature tool may be put into Puget Sound to measure water temperature. The tool kit will appear in front of the students when a specific button on the wand is pressed. The temperature tool is represented as a red thermometer, the greenhouse gas tool is represented as a green triangle, the rainfall tool is represented as a blue water column, and the time portal is represented as an opaque white circle. When students place their cyber hand in the proximity of the desired tool it changes to a different color shade, indicating that they may now activate it by pushing a button on the wand. When activated, the numerical value of the current reading for the tool selected is displayed in a pop-up box at the bottom of their HMD screen.

When the time portal tool is activated a large stone-rimmed portal appears and the current year is displayed in the pop-up box. Students may then reach out with their cyber hand to activate the year selector, represented by a ball that slides around the circular stone rim. As students move the ball around the rim the pop-up box display scrolls through years. When the ball is released the year currently in the display is selected. The student travels to the selected year by *flying* through the center of the portal. Upon exiting the time portal into the selected year, the environment will appear to be visually the same. One important exception to this is that if global warming has occurred or decreased over time, the shoreline water level of Puget Sound will rise or fall accordingly, indicating that polar ice caps are thawing or refreezing. Otherwise, to discover what changes have taken place over time, students must access their tool kit, take measurements, and compare these measurements with readings they have taken in other years.

To cause environmental changes that will occur over time, students are able to adjust three large wheels in GCW that represent: (1) the amount of green plant biomass in the world, symbolized by trees; (2) the amount of heavy industry in the world, symbolized by factories; and (3) the impacts of population on the world, symbolized by cars. An icon of a tree, factory, or car is at the base of each wheel to clearly identify the variable to be adjusted. Using the simple metaphor of a wheel to represent complex phenomena is beneficial in that it allows students to focus on the process of global change as it progresses over time. Using their cyber hand, students can hold on to and rotate wheels clockwise to increase the amount of a variable in the world and counterclockwise to decrease the amount. The current value of the wheel selected is displayed in a pop-up box in their display and changes continuously as the wheel is rotated.

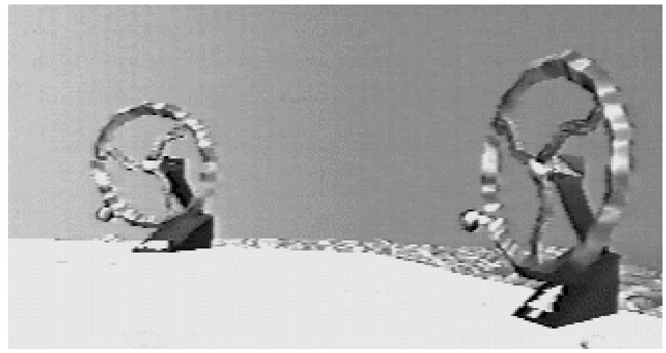

Figure 4. Two of the global variable wheels of GCW

The general process for using GCW in a structured exercise involves taking current environmental measurements with the tools of the tool kit, traveling into the future to make additional measurements and to look for trends, changing the values for the global variable wheels, and traveling farther into the future to observe how environmental outcomes have been altered by those changed values. An underlying model runs through a cycle of global warming, consisting of the warming and re-cooling of the atmosphere, approximately every 300 years and regulates the behavior of GCW over time. The students unknowingly enter into GCW at a time when the model is just beginning a downward cycle leading to a collapse of the fisheries, highly polluted air, severe drought, and coastal flooding. The cycle continues downward for a period of almost 200 years before conditions begin to improve, in theory because polluters at some point learn to stop polluting or simply die off. Altering values for the global variable wheels can dramatically impact the way the model behaves over time. Thus, in focusing strictly on a time frame within the initial downward cycle, students can experiment with theories regarding adjustment of the wheels in efforts to reduce or reverse the downward trend.

4. STUDY DESIGN

Our primary objective was to simply document middle school science students studying global warming demonstrating the propensity to collaboratively expand upon classroom-based subject matter knowledge while immersed in a VLE. However, since subjects came from three separate 9th grade classes the natural boundaries provided by the class units were used to further explore collaboration within an immersive VLE. Class sections served as either control or collaborative treatment groupings. Group 1 served as a control where subjects entered GCW without a partner and were to perform tasks largely on their own, receiving minimal assistance from experiment administrators. Group 2 subjects entered GCW in pairs who were encouraged to collaborate freely with peer partners in performing tasks, yet received minimal assistance from experiment administrators.

Group 3 subjects entered GCW singly with an experiment administrator who played the role of an expert advisor by answering all questions, actively provoked reflective thinking, and directly assisted subjects when they experienced difficulties while performing tasks.

All subjects participated in a series of familiarization exercises prior to running the study. These exercises were intended to acquaint subjects with the experience and equipment of VR and consisted of two preliminary visits to the school to allow all subjects the opportunity to freely explore the features of GCW during 20-minute sessions. Such familiarization is critical since research [30] has indicated that students may have initial difficulties in: (1) learning to navigate and feel comfortable in the 3D VLE environment; (2) handling the cumbersome HMDs; and (3) learning the control schemes of the wand buttons.

In the week prior to running the study, teachers devoted class instruction time to exploration of the topic of global warming. This instruction served as an overview and was only intended to familiarize subjects with the basic concepts, terminology, and debates surrounding global warming. Prior to participating in the study students also received instruction and practice on creating concept maps, since a concept mapping exercise was used to measure domain knowledge organization among subjects. Concept mapping has been demonstrated to be an effective tool in education both as an evaluation device and for the promotion of meaningful learning [18].

For the activities of the study, researchers administered GCW tasks using a standard protocol to preserve treatment fidelity. Each individual or pair involved in the study participated in the same activities, though for peer pairings specific tasks were divided to encourage collaboration. In a briefing just prior to entering GCW subjects were told that they were part of a scientific team hired by Virtual Seattle (VS) to conduct environmental research. Subjects were informed that residents of VS needed to know what the future environmental impacts of present day human activities might be. If it is determined that current human activities will be harmful to the VS environment of the future, VS leaders would appreciate advice on what they must change in order to keep things environmentally balanced. Upon entering the VLE subjects were instructed to conduct a scientific experiment. Subjects initially took three sets of air temperature, greenhouse gas, and rainfall measurements over a 50-year period at 25-year intervals and adjusted the three global variable wheels as desired.

Though subjects typically identified a consistent trend in the data they collected, the behavior of GCW was expected to, and often did, conflict with expectations that might evolve from some of the generally accepted notions for global warming processes. For example, rainfall in the local VS environment decreases over the period observed. This may contradict the expectation that, on an overall global basis, rainfall amounts will increase in an era of global warming. This behavior of the GCW model does, however, remain consistent with the belief that global warming will cause weather patterns to *shift*. A possible explanation would be that a normally wet *local* VS environment could become dryer if rainfall increased substantially elsewhere. Subjects often failed to notice the supporting evidence of fluctuations in the Puget Sound shoreline water level. Thus, based upon personal understanding of and expectations for global warming some subjects had a hard time deciding whether or not to label what they observed as a process of global warming.

In practice, the GCW model allows for wide variation in possible outcomes and most subjects experienced some difficulty in accurately predicting the outcomes of their changes to the global variable wheel settings. For example, increasing the biomass variable alone would not reverse environmental deterioration and this may conflict with a misconception that global warming occurs primarily as a result of worldwide deforestation. The ability of GCW to (1) create this kind of conflict and (2) provide challenging outcomes are valuable features in terms of what we know about collaborative problem solving. In consideration of their final measurements subjects were asked to reflect upon their hypotheses, expectations, and the outcomes of their experiments. Subjects were asked to draw conclusions regarding what they observed and to reflect upon their overall experiences with GCW.

5. FINDINGS

Though efforts were made to thoroughly familiarize subjects with GCW and train them on navigation and virtual tool skills during two prior visits to the school, many of the subjects in each group were still unsure of how to go about performing their tasks in a timely manner. Many subjects experienced problems trying to remember how to use the navigation and selection controls of the wand. The Group 2 peer-pair of Allison and Jessica provide an example of this in the following exchange:

> **Randy**: Well let's see, we're at 2057, let's go up to about the year two one zero zero.
> **Jessica**: Humh!
> **Randy**: Let's jump a little.
> **Jessica**: I lost my hand!
> **Randy**: Oh yeah, ah, yeah, hold on.
> **Allison**: I see your hand!
> **Jessica**: I do too, but I can't get that, like, ball!
> **Randy**: Yeah you're going to have to fly closer to it rather than walk closer to it.
> **Jessica**: Oh, okay.

Some subjects may have been hampered by the different nature and demands of the study during their final excursion to GCW, as Group 1 single-subject Jessica demonstrates:

> **Randy**: …let's get you going in this one here.
> **Jessica**: Will we still grab with the same tool and all that stuff?
> **Eileen**: Yeah. Before you were together, this time you're all by yourself, so you're the only one in here except Randy can talk to you.
> **Jessica**: That's kind of spooky, whoa!

And some thought that GCW had been completely changed from when they last saw it even though no changes had been made, as evidenced by the following exchange between Allison and Jessica below:

> **Allison**: Okay. Whoa! Things look different this time. [Hums] Jessica?
> **Jessica**: Yeah?
> **Allison**: Are you, like, taking the measurements?

Because of these difficulties, and owing to the time and scheduling restrictions encountered when working in a school classroom environment, researcher interaction with subjects of all groups evolved into a more active role than was originally envisioned. In fact, all three groups required substantial collaborative scaffolding from experiment administrators throughout the exercise. An analysis of the collaborative role researchers played in administering the GCW experiment reveals strong ties to what Brown and Palincsar [2] label Reciprocal Teaching. In Reciprocal Teaching, expert scaffolding of group discussions is accomplished by ensuring that four strategic activities are practiced routinely: questioning, clarifying, summarizing, and predicting. A critical point is that these strategies are to be practiced within an appropriate context and are not intended to be exercises that are mastered individually and randomly used. Throughout the GCW exercise, subjects were encouraged to summarize findings, question observations, clarify understandings, and predict outcomes. By either embedding these strategies into the tasks of GCW or incorporating them through a direct personal intervention, an expert scaffolding of learning processes was accomplished. Researcher scaffolding served the primary purpose of keeping the activities of GCW focused and moving steadily towards task completion.

In spite of these frequent researcher interventions, the integrity of the overall experiment design was maintained. For example, subjects of Group 3, who visited GCW in the company of an experiment administrator who directly answered all of the students' questions and actively provoked reflective thinking, received a much higher level of support throughout their experience. The following exchange with Joe of Group 3 provides an example:

> **Randy**: And what, ah, now as far as all the indications for, we know that the temperature is increasing, we know that the greenhouse gases increased, but the rainfall's actually gone down. Does that sound right? Does that…
> **Joe**: Well…
> **Randy**: …seem reasonable?
> **Joe**: Not really, I don't know. I guess not!
> **Randy**: Well, I'll tell you. The thing about rainfall is that with global warming, it'll actually increase…
> **Joe**: Oh!
> **Randy**: …but that's on a global level. What's…
> **Joe**: Oh! Climate is changing in the city!
> **Randy**: That's right! The climate will change in different areas, and so wet areas may become dry areas - so the weather patterns will shift. And so I think that's why we're seeing less rain in Seattle, even though in other places it may be - the rain actually may be increasing.

Subjects of Groups 1 and 2 were not provided with insights beyond the conclusions they arrived at on their own and peer-pairs were encouraged to keep on the task, interact with each other, and reflect on what they were experiencing. As demonstrated by the following exchanges with the Group 2 pairing of Tyler and Chris, there was often a period of initial struggle:

> **Randy**: Okay let's try the rain gauge.
> **Tyler**: (inaudible) its at fifty-two.
> **Randy**: Okay, so do you know what's that done or…
> **Tyler**: I think it's increased, I can't remember.
> **Randy**: Well it was fifty-five.
> **Tyler**: Oh, it did?
> **Randy**: So, you checkin' this out Chris?
> **Chris**: Um, I'm trying to.
> **Randy**: Can you see the numbers?
> **Chris**: Uh, 52 point 587612.

However, subjects often became much more engaged in the experiment after a warm-up period. Tyler and Chris needed much less prodding later on when making decisions regarding the turning of the wheels:

> **Tyler**: Chris, what do the three wheels represent?
> **Chris**: Ah, one right here is trees, and then the other one, is factories, and then, there's cars.
> **Tyler**: Cars?
> **Chris**: Yeah.
> **Tyler**: Ah.
> **Chris**: So what should we do with cars?
> **Tyler**: Ah. I think we should take some cars out add some trees.
> **Chris**: Okay. Let's see, how do we take away?
> **Tyler**: We go counter-clockwise.

Gender issues played a role as well. Female pairs were far more likely to actively seek out and spend time with each other. They also were seen to engage in informal collaboration and interpersonal interaction more often during the exercise than their more stoic male counterparts. The following excerpt from the Allison-Jessica peer pair provides an example of this as the administrator tries to keep the subjects on track by having them take a measurement:

> **Allison**: Is this the wheel I have to turn?
> **Randy**: Well, yeah…
> **Jessica**: I'm, like, on the ground.
> **Randy**: Yeah.
> **Allison**: Jessica!
> **Randy**: But we're going to take a few more measurements.
> **Jessica**: How do I go up?
> **Randy**: Ah, if you look down and fly backwards.
> **Jessica**: Look down and fly backwards?
> **Randy**: That's a good way to do it - fly backwards!
> **Jessica**: How do you fly backwards?
> **Randy**: There, you're doing it!
> **Allison**: Push!
> **Randy**: You just did it. Oh yeah!
> **Jessica**: Ah!
> **Randy**: Jessica, yeah there you go. See?
> **Jessica**: Okay
> **Randy**: All right, now, we need to take some more measurements.
> **Allison**: Jessica where are you?
> **Jessica**: I don't know, where are you?
> **Randy**: Allison, you, yeah you need to fly down to the floor - she's down there on the floor someplace.
> **Allison**: On the white floor?
> **Randy**: Yeah, just the kind of marbly looking floor.
> **Allison**: Oh I think I see you!
> **Randy**: Yeah there she is!
> **Jessica**: Where are you?
> **Allison**: Hi Jessica!
> **Jessica**: I don't see you.
> **Randy**: Okay.

Allison: Right there, you see me?
Randy: Jessica…
Jessica: No.
Randy: …let's take some more measurements now.
Jessica: Okay.
Allison: I'm right there now.
Jessica: Oh! [Laughter]
Allison: [laughter]
Jessica: Okay.
Allison: Okay.
Jessica: Oops, um…
Randy: Allison?
Allison: Uh-huh?
Randy: Ah, okay, I don't think you can see, but Jessica what did the measurements come up at?
Jessica: It's 34.608257.

Brown and Palincsar [2] cite the importance of other roles students assume in the process of collaborative group learning. All GCW subjects were expected to shift between the primary roles of Executive and Record Keeper as part of the GCW task. Most subjects were able to do this in all three GCW groups and it was a required activity for the Group 2 peers. A dynamic role structure in the GCW learning environment is highly desirable since it allows subjects to become active participants at a level in which they are comfortable, thus enhancing problem solving and concept development. Forman [13], for example, uses a "bi-directional zone" to describe enhanced problem solving abilities in peer groups where each group member provides expertise in a certain area, thereby raising the level of the entire group.

Peer collaboration played a strong role in student engagement with virtual world activities. The ability of the subjects to communicate with each other through the intercom in a normal speaking voice from within the world facilitated comfortable and casual conversations between peers, sometimes as though they were speaking to each other in private. All collaborative activities enhanced the experience and the ability of guides to speak to students through the HMD speaker system appeared to increase their sense of presence, as previously described. In addition, it was remarkably easier for expert advisors to advise subjects from the vantage point of a collaborative entity within the VLE, as opposed to communicating by voice alone through an audio connection.

Subjects in all groupings were seen to be eager to engage in collaboration, and some were highly communicative. As they navigated through the world or performed requested tasks, some subjects were engaged in near constant conversation regarding where to go, what to do next, and how to do things. While immersed in the VE, many subjects were physically active as well and were seen pointing at virtual objects with their free hand in the real world. Several students were quite surprised that they had walked almost halfway across the room when we removed the HMD. They had assumed that they stood fairly still while they were flying around in the VE. Others bumped into walls and chairs completely oblivious to the real world around them. In sum, we know that the students were highly motivated, very willing to work collaboratively, interested in exploring virtual space, and capable of performing the investigative tasks of GCW. Further research that focuses more closely on how these kinds of experiences impact overall learning processes is warranted.

A 24 question post-study survey was used to probe subject content knowledge, attitudes, experiences, and general characteristics. Some subjects reported problems seeing clearly while in the HMD, and about 5 percent reported some kind of malaise (dizziness or disorientation). Most of these problems appeared to diminish as subjects spent more time in the VLE. In spite of the problems, almost all subjects reported the experience as being highly enjoyable and most said they would want to repeat the experience. Ratings of presence were high for all subjects.

A number of questions on the survey directly probed declarative knowledge regarding global warming. Of particular interest were the responses to a question asking what would happen to annual rainfall amounts during a period of global warming. The majority of subjects responded that annual rainfall would decrease, clearly on the basis of what they had just observed in GCW. However, they had received prior classroom instruction that annual rainfall on a *global* basis is likely to increase, but that *regional* variations may occur. With GCW fresh in their minds the "increase" option was not expected to be very appealing and, in fact, very few subjects chose that option. However, the "vary by region" option was largely ignored as well. This seems to indicate that the GCW experience was powerful enough to override other channels of instruction, at least for the short term. This is one case where the guided subjects of Group 3 had a clear advantage since they were explicitly told that GCW represented a regional variation. Still, more that forty percent of Group 3 chose the "decrease" option.

Another question asked subjects to write down the single most important thing to be concerned with when thinking about global warming. Of particular note here was the difference in the variety of responses between groups. The responses from Group 3 were exclusively focused upon the three basic concepts embodied by the global variable wheels of GCW: (1) environmental impacts; (2) greenhouse gasses; and (3) pollution. Group 1 singles provided a little more variety in their responses and included concepts that were not overtly part of the GCW experience, such as "conservation". Group 2 peer pairs provided the most varied responses of all and included concepts such as "animal extinction" and "recycling". It seems likely that the direct instructional nature of the Group 3 experience strongly influenced subject perceptions of the relative importance of concepts related to global warming. This can be good, but it can also be bad. We must be very careful about unwittingly embedding misconceptions in our VLE designs. The above examples deliver additional justification for providing robust collaborative VLE experiences in conjunction with regular classroom instruction and debriefings.

All subjects were able to make use of their existing understanding of the global warming topic towards creating and testing theories within GCW. Some students described their time in GCW as a learning experience, although for others it appears to have been merely a confirmation. Indeed, some students were more successful than others in bringing the environment to a more stable state, however any differences in ability to make appropriate changes appear to have arisen from individual learner differences rather than from the type of collaborative support received. Results of the post-study concept mapping exercise show scores ranging widely for all three groups. This is a crucial lesson learned from this study. Our subjects responded in radically different ways to the experience of being immersed in a VLE and they brought a variety of prior knowledge, individual character, and life experience to bear on the given task. For some it was almost second nature, and for others it remained alien or problematic. Clearly, we know very little about the nature of human interaction within VEs, but it seems likely that collaborative activities can play a significant role in reducing the negative impacts of such strong individual differences.

6. CONCLUDING REMARKS

The GCW study was an exploration of VLE-based collaboration in an everyday school social environment. In coordinating our research efforts with ongoing science classroom activities we were successful in demonstrating how an immersive VLE experience can be integrated into students' regular classroom activities. We believe this study supports the notion of a general educational effectiveness for future applications of GCW and other IVR applications. While HMD-based virtual reality does not represent the sole means of providing collaborative activities within VLEs, evidence gathered so far supports our contention that the GCW system does constitute a valid approach to the task.

The collaborative, multi-participant, immersive, and communicative qualities of the GCW experience combine to create a truly unique approach to VLEs. GCW's audio communication capabilities successfully allowed students and instructors to talk among themselves from within the GCW environment. This was important since collaboration between peers and instructors, or both, was a necessary element in helping students get the most out of the GCW experience. In general, the primary goal of demonstrating a propensity for subjects to collaboratively learn while using a VLE in conjunction with everyday classroom activities was met.

This research indicates that some method of expert scaffolding is necessary within the kinds of VLEs we are capable of building today. Yet, this study was not successful in identifying the kinds of specific collaborative strategies that would be most suitable for VLEs since many members in each group experienced success in completing the tasks required. In fact, post-study concept map aggregate scores for the each of the three groups reveal large individual differences among the subjects. These considerations make a strong case for employing collaborative strategies that allow students to assume roles in a VLE that both: (1) allow them to participate at a level they are initially comfortable with; and (2) provides opportunities to contribute preexisting expertise and to shift roles as expertise increases.

While the study provides no direct evidence that collaboration within immersive virtual environments aided the process of conceptual change, we observed subjects dealing with intellectual conflicts, articulating beliefs, and co-constructing theories while interacting with the GCW environment. These factors are all known to contribute to successful conceptual change and we have reason to believe that lasting conceptual change can, indeed, occur as the result of meaningful interaction within a VLE. In addition, we observed subjects engaging in friendly, non-challenging, and positive ways towards developing concepts and testing theories of global warming. Camaraderie may yield yet another means of promoting conceptual change in the face of conflicts encountered in the real world situations of VLEs.

We believe immersive VLEs can provide beneficial educational experiences unobtainable by any other means if they focus strongly on the affordances that are specific to the technology. These include: presence, interaction, autonomy, rich visual metaphors, scale, time, distance, and safety. Affordances central to the GCW experience included: (1) the sense of presence in and ability to interact with a world of consequence; (2) the ability to travel through time to gather data and test theories; (3) the provision of rich visual metaphors, such as the global variable adjustment wheels; and (4) autonomy in the form unexpected outcomes. Observation and student reports indicate that be these capabilities provided most students with an enriched learning experience. Also, the learn-by-doing constructivist nature of the GCW exercise required substantial individual effort while necessitating collaborative activities in all cases. Again, observation and student reports reveal that these factors provided students with an enriched learning experience.

While the potential for VR to facilitate collaborative learning experiences has been demonstrated and appears to have great potential, much more research is needed before effective collaborative learning strategies can be developed. It is anticipated that these strategies will vary, depending on the kind of educational experience desired and the specific learning environment employed. However, for this potential to be realized, designers of hardware, software and instruction must make sure that it is easy for multiple participants to collaboratively navigate and perform tasks in VLEs. This requires improvements in overall system performance and on today's interface devices, including improvements in spacialized 3-D audio systems, less cumbersome HMDs, simpler wands, and the eventual introduction of haptic (force feedback) devices. The ongoing research involving GCW is worthwhile considering that the networking of multi-participant, collaborative virtual environments appears to represent a significant trend for future applications of VR both within and outside of the educational domain.

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