Designing for Motivation and Usability in a Museum-based Multi-User Virtual Environment

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This National Science Foundation (NSF) funded research project is creating and evaluating graphical multi-user virtual environments (MUVEs) that use digitized museum resources to enhance middle school students' motivation and learning about science and its impacts on society. MUVEs enable multiple simultaneous participants to access virtual contexts, to interact with digital artifacts, to represent themselves through "avatars," to communicate with other participants and with computer-based agents, and to enact collaborative learning activities of various types. Initially, MUVEs were based only on textual descriptions); now, many MUVEs are graphical in nature, or use graphics to enhance textual descriptions. Our project's educational environments are extending current MUVE capabilities in order to study the science learning potential of immersive simulations, interactive virtual museum exhibits, and "participatory" historical situations (http://www.virtual.gmu.edu/muvees/). To accomplish this, we have built our own MUVE shell based on the Sense8 WorldToolKit (http://www.sense8.com/).

Our MUVEs are not stand-alone learning environments, but instead are designed for use in a classroom context, supplemented by conventional instructional activities such as textbooks and teacher-led discussions. Hard-copy outputs, including both lab-notebook answers and written letters to the "mayor" provide methods for teacher assessment; teachers use them to determine when to "promote" a student to the "next level" in a unit. Our virtual learning environments function on bandwidth as low as a 56K modem and on Windows desktop computers with at least 450 Megahertz processing speed and 64 Megabytes of RAM, well within the specifications of machines currently being purchased by schools.

Our project is studying how the design characteristics and usability of MUVE learning experiences affect middle school students' motivation and educational outcomes. We are focusing on the extent to which guided inquiry and mentoring using digitized museum artifacts in virtual contexts can aid pupils' performance both on classroom assessments and on high-stakes tests related to national science standards. In this research, we are studying pedagogical strategies that foster strong learning outcomes across a wide range of individual student characteristics (e.g., prior experience with computers, knowledge about and interest in science, gender, ethnicity, linguistic proficiency in English). Interaction in the MUVEs involves substantial reading and writing, so we are providing all student materials in both English and Spanish to study the effects of this intensive textual interaction in enhancing multi-lingual communication and literacy.

In particular, we are working to dramatically improve the educational outcomes of the bottom-third of students, pupils who even by middle school often have given up on themselves as learners. These students are disengaged from schooling and typically are difficult to motivate even by good teachers using inquiry-based pedagogy. We are studying whether educational MUVEs with deep content and challenging activities that resemble the entertainment and communication media these students use outside of school can reengage them in learning. Our research is also examining the implementation process needed to successfully integrate MUVEs in typical classroom settings. Our long-range goal is to develop "replacement" units that—through simultaneously developing students' knowledge in science, mathematics, history, and social studies—enable the teaching staff to utilize inquiry methods capable of covering the same span of content in a similar amount of time required by presentational teaching of this material one topic at a time. Given current educational "reforms" based on an overcrowded curriculum driven by high-stakes, low-level tests, this is essential for any scalable curricular intervention.

Partners in this research are Harvard's Graduate School of Education, the Virtual Environments Lab at George Mason University, the Smithsonian's National Museum of American History (NMAH), and Thoughtful Technologies, Inc. The development team includes education researchers, science educators, instructional designers, computer scientists, museum archivists and exhibit designers, graphic artists, scientists, and middle-school science teachers from both public and private schools. We are documenting our design process to develop heuristics generalizable to other groups developing educational multi-user virtual environments. This study reports on a “River City” curriculum unit on which we conducted pilot implementations in public school classrooms in Boston, MA.

DESIGN AND DEVELOPMENT

Our initial design started with the problem areas identified by science teachers. They were interested in experimenting with something that addressed difficult parts of the curriculum, not the relatively easy parts for which there were already several acceptable instructional strategies available to them. For middle school, the teachers identified experimental design as most difficult concept for students to learn and the one for which teachers were most eager to find an alternative instructional method. In particular, it was thought that an activity in which students had to behave as scientists while they identified a problem through observation and inference and then formed and tested hypotheses would be most valuable. We also wanted something that would be easy for teachers to use in the classroom, so we incorporated hard-copy “lab notebooks” which students use throughout the unit to guide their inquiry while providing a familiar way for teachers to assess student progress through the unit and learning of the science content.

We have developed two prototype middle school science curriculum units, each based around the national science standards, content typically covered in the middle school science curriculum, and the types of investigative process skills necessary for students to do an independent science fair project. Each unit consists of a multi-user virtual environment with virtual contexts and digital artifacts that directly and implicitly guide learner investigations. Student materials for one of the units are in both English and Spanish. Our first curriculum prototype (the River City Unit) centers on content in biology and ecology and is the topic of this paper. The second curriculum prototype (the Bicycle unit) focuses on the physical and material sciences and is centered around problems of bicycle design related to Newtonian motion.

The River City unit is based on students collaboratively investigating a virtual “world” consisting of a city with a river running through it, different forms of terrain that influence water runoff, houses, industries, and institutions such as a hospital and a university. The learners themselves populate the city, along with non-player characters (NPCs), digital objects that can include audio or video clips, and computer-based agents. River City contains over fifty digital objects from the Smithsonian's collection, plus "data collection stations" that provide detailed information about water samples at various spots in the world. Figure 1 is a screen shot depicting a "birdseye" view of this city. (All figures are at the end of the paper.)

River City is typical of the United States in the late nineteenth century; Figure 2 depicts how we use museum artifacts to illustrate building exteriors and street scenes from that period in history. Content in the right-hand interface-window changes based on what the participant encounters or activates in the virtual environment. Dialogue is shown in the text box below these two windows; members of each team can communicate regardless of distance, but in-team dialogue is displayed only to members of that team. Participants can choose to interact either within their team or with all participants in the MUVE at that time. To aid their interactions, participants also have access to one-click interface features that enable the avatar to express (through stylized postures and gestures) emotions such as happiness, sadness, and anger. These interface features also allow looking upward or downward and seeing the world from a first-person perspective or from behind one's own body in a third-person viewpoint.

Multiple teams of students can access the MUVE simultaneously, each individual manipulating an avatar through their computer. In our implementations, the class is divided into teams of two to four students, which are "sent back in time" to this virtual environment. The lab notebook the student teams use asks the class to help the city solve its environmental and health problems, which are directly related to middle school science content. To accomplish this, the students must collaborate to share the data each team collects. Beyond textual conversation, students can project to each other "snapshots" of their current individual point of view (when someone has discovered an item of general interest) and also can "teleport" to join anyone on their team for joint investigation. In-group collaboration is visible only to other group members. Each time a team reenters the world, several months of time have passed in River City, so that learners can track the dynamic evolution of local problems.

Learners are engaged in a "participatory historical situation" in which they can apply tools and knowledge from both the past and the present to resolve an authentic problem. In this "back to the future" situation, students' mastery of 21^{st} century classroom content and skills empowers them in the 19^{th} century virtual world. Figure 3 shows the 19^{th} century laboratory equipment representative of what students can use to aid themselves in River City. An eventual goal of our work, not currently implemented, is the capability of interaction with some digital artifacts. For example, were a learner to double-click on a piece of apparatus, such as a microscope, the corresponding avatar would look through a virtual microscope; and the image from the microscope slide would appear in the right-hand interface-window.

Figure 4 presents water quality data from one of eleven water-sampling stations in River City. Potentially, at the high school level, this could link to virtual laboratory equipment applications such as the irYdium project at Carnegie Mellon University (http://ir.chem.cmu.edu/irproject/***),*** so that students could conduct their own analyses rather than receiving the experimental results. Through data gathering, students observe the patterns that emerge and wrestle with questions such as "Why are many more poor people getting sick than rich people?" Multiple causal factors are involved, including polluted water runoff to low-lying areas, insect vectors in swampy areas, overcrowding, and the cost of access to medical care. Eventually, we hope to develop the capability for participants' avatars to become ill if they behave in ways that trigger these factors in the environment, thus increasing students' sense of immersion in the world.

Throughout the world, students encounter residents of River City and "overhear" their conversations with one another. These nonplaying characters (NPCs) are computer-based "agents" who disclose information and indirect clues about what is going on in River City [Figure 5]. As with the content displayed in the right frame, the phrases "spoken" by NPCs vary according to a student's level.

The main goal of the MUVE is to teach students the skills necessary for scientific inquiry, such as would be important in conducting investigations for a science fair project. This goal follows the National Science Education Standard A for scientific inquiry in 5-8 grades (http://www.nap.edu/readingroom/books/nses/html/6d.html). The emphasis in the MUVE is on identifying a problem, and therefore, River City has multiple lines of potential exploration. As mentioned above, there are 3 main strands of illness in River City. Some inhabitants have intestinal upsets from water contaminated by sewage. The sewage reaches the river from deliberate outflow of the flush toilets newly introduced to the wealthy homes in the mountains. This contaminated water flows downstream to the swampy lands behind the tenement homes used by the poor as potable water. This potential strand of investigation aligns with Standard F, Science in Personal and Social Perspectives, and demonstrates to students the complications of human activity as well as the effect of differing living conditions on disease transmission (e.g., the wealthy live in single family homes upstream, while the poor live downstream in crowded conditions promoting disease contagion). In addition, some of the city wells, used by middle class residents and hotel guests, are also contaminated from street runoff of manure. Investigating the water contamination integrates the students' knowledge of the water cycle, Standard D, Earth Science, with the historical aspects of River City.

The second disease strand is the introduction from outside of tuberculosis and the patterns that emerge of its spread throughout River City. The students' awareness of the passage of time is particularly interesting for this disease and for the last, malaria. Malaria, endemic to many areas of the U.S. in the 1800's, follows the life cycle of its carrier, the mosquito. As a result, as the students log in each day, they are able, if this problem is of interest to them, to follow the rise and fall of new cases of malaria from summer to winter and back again. These three diseases were chosen to represent three different disease vectors: water-borne, air-borne, and insect-carried, and align with Standard C, Life Science.

These three disease strands are integrated with historical, social and geographical content to allow students to experience the realities of identifying a problem, from within a content-rich environment, to investigate. Many students learn in schools the unrealistic view that there is a single right answer in science, easily discernible. In exploring River City, however, students are each guided in teams to make a unique hypothesis regarding one of many problems, based on their own interest. At the end of the project, they compare their research with other teams of students to discover the plethora of potential hypotheses and avenues of investigation available for exploration.

During their time in the MUVE, students answer questions in a Lab Notebook, which the teachers later use for assessment purposes. The Lab Notebook starts with questions that guide exploration of the environment and develop mastery of the interface, building towards later investigations that are content specific and require completing a data table based on the water samples encountered in River City. At the end, students write a letter to the mayor of River City describing the health and environmental problems they have encountered and making suggestions for improving the life of the inhabitants.

Over time, we plan to add various capabilities that may enhance participants' motivation and engagement. In addition to features listed earlier, these include:

- An avatar can gain new powers through mastering skills and knowledge. Learners who master science content and investigative skills can attain higher "levels of performance" in which they can use doors and objects that lower level participants cannot. To keep the interactions collaborative and to help all participants learn, part of attaining a level is based on helping a less adept student master content and skills through peer mentoring, thus keeping all students on close to the same levels.
- As students succeed in resolving problems in River City, new images can appear in the world (clearly labeled as pseudo-historical objects) in which the learners are shown as co-habiting the historical environment with figures from the past. These non-player-character (NPC) avatars can provide specific information about the environment and their lives, information necessary for identifying and solving problems related to the curriculum on which the unit is based. .
- Historical figures can appear as avatars to guide students in resolving the problems in River City (parallel to encountering an actor playing Thomas Jefferson on a visit to historic Williamsburg). For example, Ellen Swallow Richards (the first woman to graduate from MIT) was a pioneer in water quality treatment and is the “patron saint” of River City. Contemporary experts such as public health officials could also at times assume avatar roles in the MUVE to illustrate present day water quality issues in the U.S. and in developing countries. Such figures could provide not only mentoring, but also role models, especially for young women and minority students fighting cultural stereotypes about learning science.
- Students can travel through time to the same location at different historical eras to develop an understanding of how use of natural resources and technologies affect both the quality of life and the environment. For example, while situated in River City during the 1960s, students could gather information from a Rachel Carson-like historical figure to assess the effect of pesticides on water quality, the environment, and crop yields. They could also have access to antibiotics for treating illnesses caused by water-borne diseases.

Videogames and chat tools that incorporate some of these features seem quite motivating to many children.

METHODS, EVIDENCE, AND RESULTS

One sixth and one seventh grade classroom in different schools with high percentages of ESL students, were identified as having access to the needed technologies. Approximately 75% of the students were on free or reduced lunch. Control classrooms were arranged with a similar, but technology-free curriculum designed for them. In the seventh grade school, the same teacher taught both classes. In the other, each classroom had a different teacher. There were 45 students in the two experimental classes, and 36 in the control, evenly split by gender.

Both qualitative and quantitative data were collected from students and teachers over the three-week implementation period. Patterns for Adaptive Learning Survey (Midgley, 2000) with subsections on science interest, thoughtfulness of inquiry, motivation, collaboration, academic efficacy, technology interest, etc and a content test, (modified from Tobin, 1999), were administered to students, pre- and post-intervention. In addition, demographic data and teachers' expectations of students' successes were collected. Observational data was collected from the test classrooms throughout the project and sporadically from the control classrooms. All teachers responded to a pre and post questionnaire regarding their methods and comfort with technology. The test classroom teachers also wrote a narrative about their perceptions of the MUVE at the end of the project.

The quantitative data was analyzed with SAS. Descriptive statistics, correlations and regression models were run. A significance level of $p < .05$ was used and checks for linearity, normality and homoscedasticity were performed at various intervals. No clear violations were noted. Preliminary results indicate the MUVE is motivating for lower ability students. Six out of seven experimental students scoring less than 35% on the content pre-test improved their content knowledge above that level, while only two of five control students did so. In addition, controlling for collaboration and science interest, the experimental group, on average, had more positive changes in motivation mastery (as measured by the PALS assessment) than did the control group. Subtest averages for students' perceptions of academic efficacy also showed significant differences between the two groups ($t=3.36$, $p<.05$), with the experimental group showing an increase of one point out of five on average as opposed to the control groups decrease of .31. We found that students did perceive different problems in the MUVE. In our seventh grade classroom, e.g., there were five different hypotheses with causes ranging from population density to immigration to water pollution. Another interesting preliminary finding is that the MUVE seemed to have the most positive effects for students with high perceptions of their own thoughtfulness of inquiry (TI). These students, on average, scored higher on the post content test, controlling for SES, science GPA, ethnicity and content pre-test score. A similar effect was seen for explaining the variation in the TI post-test.

IMPORTANCE OF THIS STUDY

Our project is extending current MUVE capabilities in order to study the science learning potential of immersive simulations, interactive virtual museum exhibits and "participatory" historical situations, particularly for low-performing students who are turned off to school and skeptical about their ability to learn. Our research to date demonstrates that MUVEs seem quite feasible as an addition to more conventional kinds of computer-based instruction. Our long-range goal is to develop "replacement" units that—through simultaneously developing students' knowledge in science, mathematics, history, and social studies—enable the teaching staff to utilize inquiry methods capable of covering the same span of content in a similar amount of time required by presentational teaching of this material one topic at a time. Given current educational "reforms" based on an overcrowded curriculum driven by high-stakes, low-level tests, this is essential for any scalable curricular intervention.

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ILLUSTRATIONS

Figure 1: Birds-eye View of River City

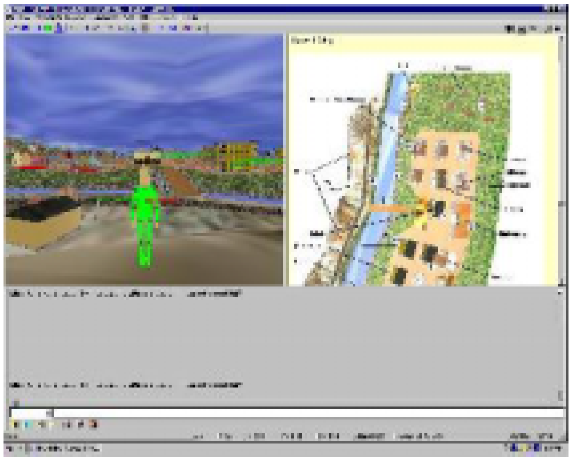

Figure 2: A Street Scene in River City

Figure 3: Lab Equipment inside a Building

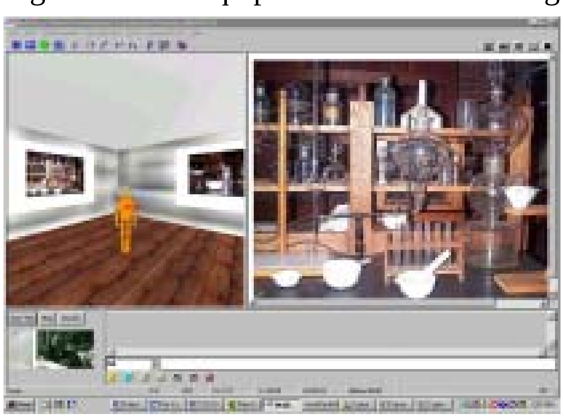

Figure 4: River water sampling station

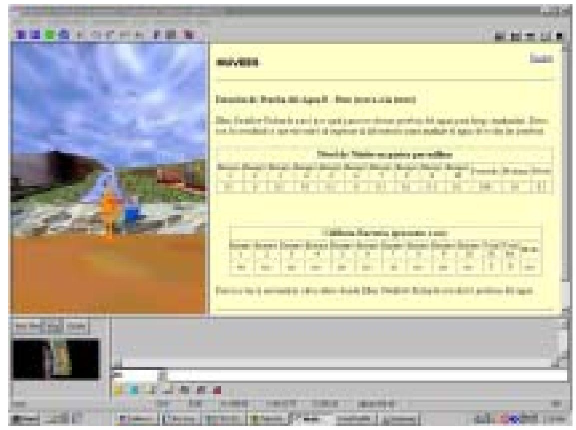

Figure 5: Screen Shot of a Non-Player Character (NPC) agent giving information.