Rethinking Pedagogy: Using Multi-User Virtual Environments to Foster Authentic Science Learning

Diane Jass Ketelhut, Temple University, Philadelphia, Pa, diane.jass.ketelhut@temple.edu
Jody Clarke, Harvard University, Cambridge, Ma, clarkejo@gse.harvard.edu
Brian C. Nelson, Arizona State University, Tempe, AZ, Brian.Nelson@asu.edu
Geordie Dukas, Harvard University, Cambridge, Ma, dukasge@gse.harvard.edu

Abstract. Science as it is portrayed in the typical K-12 classroom bears little resemblance to science as practiced by scientists, relying heavily on presentational pedagogies. To counter this, the American Association for the Advancement of Science, the National Research Council, and the National Science Teachers Association have all called for a stronger emphasis on having students perform scientific inquiry in the classroom. Yet this has proven challenging to do. How can schools replicate authentic science experiences in the classroom? This paper reports on the benefits of using Multi-user Virtual Environments to create authentic science experiences for middle-school students that allow them to engage in the processes of scientists. Our research indicates that low self-efficacy students and those with poor initial knowledge do as well as those with average self-efficacy and better than those learning with more traditional inquiry pedagogies. High self-efficacy students, however, do better with the traditional inquiry methods.

Introduction

Despite movements within the past twenty years to change how science is taught in schools, science education in the United States is still in crisis. Recent reports reveal that high school students are still not enrolling in science courses, the US trails other countries on national tests, and that minorities and women are not opting for doctorates or careers in science (National Science Foundation, 2001; Grigg, Lauko, and Brockway, 2006; Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 2007). These reports tell a story of students' declining level of interest and expertise in science that has implications for learning science across the globe.

One possible contributing factor is pedagogy. A glimpse into typical K-12 classrooms reveals that current science teaching and learning still bear little resemblance to science as practiced by scientists (Chinn & Malhotra, 2001). While the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and the National Science Teachers Association (NSTA), amongst others, have all called for a stronger emphasis on inquiry, replicating authentic science experience in the classroom has proven difficult. This is partially due to the lack of teacher understanding of what inquiry is and how to implement it, and partially due to the lack of the intense resources needed to conduct high-quality inquiry activities in the classroom (The National Academies, 2005; Nelson & Ketelhut, 2007). Thus, students are deprived of a pedagogy that has been shown to improve content-based test scores even for traditionally low-scoring subpopulations (Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier, et al., 2004).

In an effort to address these issues, we are exploring an emerging pedagogical approach for teaching authentic science as inquiry: multi-user virtual environments (MUVEs). MUVEs are online digital worlds where multiple participants can collaborate on shared experiences. MUVE participants take on the identity of an avatar, one's digital persona in a virtual world, and communicate with other participants via gestures and text chat. In the graphical virtual worlds within MUVEs, participants also interact with digital objects modeled after their real-world counterparts and computer-based characters.

MUVEs have been used in science education to offer professional development for teachers (Annetta and Park, 2006); develop science-based activities that promote socially responsive behavior among student participants (Kafai, 2006; Barab, Arici, & Jackson, 2005); mentor students on science fair projects (Corbit, Kolodziej, Bernstein, & McIntyre, 2006); and support situated opportunities for students to develop and practice scientific inquiry skills (Nelson & Ketelhut; 2007; Clarke, Dede, Ketelhut, Nelson, 2006).

In this paper, we describe the ways in which we are using one educational MUVE, *River City*, to engage students in authentic practices of science. After presenting the design of our MUVE and how it replicates the real-world practices of scientists, we will examine recent research findings indicating that students with low self-confidence in scientific inquiry make significantly larger gains in content mastery using the MUVE than those using a paper-based equivalent. Additionally, we will examine the journey of a single student from "sleeper" to scientist.

Context
Scientific Inquiry

The goal of classroom scientific inquiry has been articulated by multiple state and federal policy doctrines (AAAS, 1990, 1993; NRC, 1996). Despite this, access for many students to inquiry-based science curricula has been limited by numerous factors, including poor teacher preparation in inquiry, lack of laboratory space and supplies, uncertified science teachers, and a culture of high stakes testing in the United States (Nelson & Ketelhut, 2007).

Further complicating the situation are the students themselves. By middle school, many students have turned off from science, believing that they cannot 'do science' (Ketelhut, 2005). This belief, termed self-efficacy, affects student behavior in the classroom, with high self-efficacy students more likely to persevere and be engaged (Pajares, 2000). Thus, even if they were offered scientific inquiry-based curricula, students with low self-efficacy would be less likely to take advantage of this opportunity.

Therefore, what is needed are curricula that can help students learn content standards via inquiry, model inquiry for struggling teachers, and enable inquiry with little reliance on costly supplies. In addition, these curricula need to include experiences that interest students and help them build a belief they can succeed, regardless of their initial self-efficacy. One possible approach that shows promise is to deliver scientific inquiry curricula via multi-user virtual environments. These game-like computer environments are familiar and engaging to students, and there is some indication that curricula embedded in them can successfully model good scientific inquiry practices for teachers (Nelson & Ketelhut, 2007). Here, we present one such MUVE, *River City*, as an example.

Inquiry and the *River City* MUVE

The *River City* MUVE is a middle school science curriculum designed around national content standards and assessments in biology, ecology, epidemiology, and scientific inquiry. In the curriculum, students work in teams of three to collaboratively investigate why the residents of *River City* are falling ill. Students travel back in time—in the virtual world—to the period in history when scientists were just discovering bacteria (for further information, see Ketelhut, 2007).

Students learn to become scientists by engaging in the inquiry practices of scientists. In the *River City* MUVE, students engage in all aspects of inquiry as defined by the National Science Education Standards (NRC, 1996). These aspects are listed in Table 1 below, with descriptions of how they are manifested in the *River City* curriculum (Ketelhut, 2007; Nelson & Ketelhut, 2007).

Table 1: How *River City* Objectives Map onto Inquiry (as defined by the NRC, 1996).

Making Observations	Throughout the curriculum students are asked to make observations and draw inferences about what they see and hear as they move around the world.
Posing Questions	Students are prompted to pose questions about the problems in *River City*. They record these and reflect on them as they gather data and make observations and inferences. Students can also pose questions of the 32 computerized residents of *River City* and elicit short sets of information.
Planning Experiments	Students are guided through a generalized process of the scientific method, where they learn how to turn their questions into hypotheses and to design procedures to test those hypotheses.
Conducting Experiments	Students conduct their experiment in *River City*. They visit a 'control world' (controlled part of their experiment for gathering data), then they visit the 'experimental world' (where their independent variable has been changed and recollect the data from the same sources). They then compare the data gathered in the two worlds and write up their results using graphs and charts.
Using tools to gather data	Students use virtual microscopes (see Figure 4) to examine water purity and numbers of mosquitoes. In addition, *River City* has an Environmental Health Meter which indicates a relative level of healthiness of an area.
Communicating Results	Students write up their results in a report to the Mayor of *River City*. They also participate in a research conference where they present and share their findings with their classmates.

Students form and test their hypothesis by applying a classic controlled experimental design. They are able to gather data in two identical virtual worlds that differ by only a single factor, their independent variable, which they choose. First, they enter the unchanged *River City* in what is termed the "control world." In this world, they not only gather baseline data but tell the software what variable they want to change. After gathering their control data, students then enter an "experimental world" that is identical in all aspects to the control world except for one factor, their independent variable. For example, if students think the illness they identified in *River City* is spreading because of mosquitoes breeding in the town's bog, they might choose to drain the bog and investigate its impact on illness. Thus, when they enter the experimental world the bog will appear to have been drained (see Figure 1). Students must then gather data from the same sources as they did in the control world in order to see the effects of draining the bog.

Figure 1. Student avatar observing the bog in the control world (on left) and the dried up bog in the experimental world (on the right).

After running their experiment, students write up their findings in a report to the mayor of *River City*. The report, based on the concept of a lab report, describes their experiment, research findings, conclusions, and recommendations for how the mayor can stop the spread of illness in *River City*. Each team of students then presents its research and findings to the entire class. The purpose of this sharing day is to model the real-world practice of scientists while helping students see the multivariate nature of the problem in *River City*.

Research Design

Research Question

In this comparison study, we investigated whether students who participate in a MUVE-based curriculum demonstrate greater gains in understanding the practices of scientists than students who participate in a similar paper-based curriculum. In the same study, we also conducted an analysis of the extent to which students develop a conception of themselves as inquiry learners.

Methodology

The study implementation was held in a northeastern city in spring of 2005 in five middle school classes taught by a single teacher. Three classes were assigned to *River City* while two used the non-computer control treatment. To determine the relative efficacy of using MUVEs to deliver authentic science instruction versus a well-designed classroom-based project, we developed a paper-based control curriculum to match each feature of the curriculum except for the delivery method. The control curriculum is similar in content, yet delivered via a paper workbook. Activities and timing were matched closely between the two, with the associated lab books based on the same outline. Both curricula contain disease transmission problems; both are set in a historical framework—*River City* is based in the mid-1800s while the control curriculum is based during the plague epidemic. *River City* uses virtual experimentation, however, and the control curriculum uses physical experimentation. For example, in *River City*, students make observations using virtual microscopes and dissecting scopes. In the control curriculum, students make observations of real objects using hand lenses and microscopes.

A multiple-choice instrument was used to assess student knowledge of and self-efficacy in scientific inquiry, and a random subset of students were interviewed before and after implementation. Students also generated a drawing of themselves in science class at the outset and a letter to the mayor at the end that were analyzed qualitatively and rated for quantitative analysis. Additionally, students in *River City* generated data including chat transcripts, online notes, and usage log files.

The content instrument consisted of multiple-choice questions assessing student understanding and knowledge of biology and scientific inquiry (estimated reliability = .86); twenty-two of the questions were on conceptions of scientific inquiry. These twenty-two questions ranged from asking students to differentiate between observations and inferences to interpreting experiment scenarios. Scores were computed by adding up the number of correct responses, which ranged from 0 to 22 with higher scores representing more content knowledge.

Since, as indicated earlier, self-efficacy can mediate behaviour and effort, we chose to control for students' entering levels of self-efficacy in scientific inquiry. This was assessed via a twelve-item subscale on the affective measure. Students rated each item on a scale from 1 (low) to 5 (high) as to how well that item fit them. Overall scores were computed by averaging the student's responses across the twelve items of the subscale, with high scores representing high self-efficacy to perform scientific inquiry. The measure has an estimated internal consistency reliability of .86 in a population of middle school students (Ketelhut, 2007).

Findings

Figure 2 illustrates the effect of being in the MUVE treatment versus the control on scientific inquiry post scores, controlling for self-efficacy in scientific inquiry and scientific inquiry pretest scores. For ease of viewing, we have only graphed low, average and high values of the pretest scores, however, this is a continuous linear variable and thus, the reader can interpolate between these values. Students who entered the project with low levels of self-efficacy did, on average, significantly better with the MUVE as opposed to the control curriculum ($p<.05$), regardless of their entering pretest scores. As self-efficacy increases to the mean, there is no difference between MUVE students and the control curriculum at any level of initial science inquiry knowledge. However, this reverses as students with high self-efficacy in the control treatment did better than those with high self-efficacy in the MUVE. Also of interest is the fact that *River City* students who entered with low initial knowledge of scientific inquiry and low self-efficacy did as well or better than all students with low to average starting pretest scores, regardless of self-efficacy.

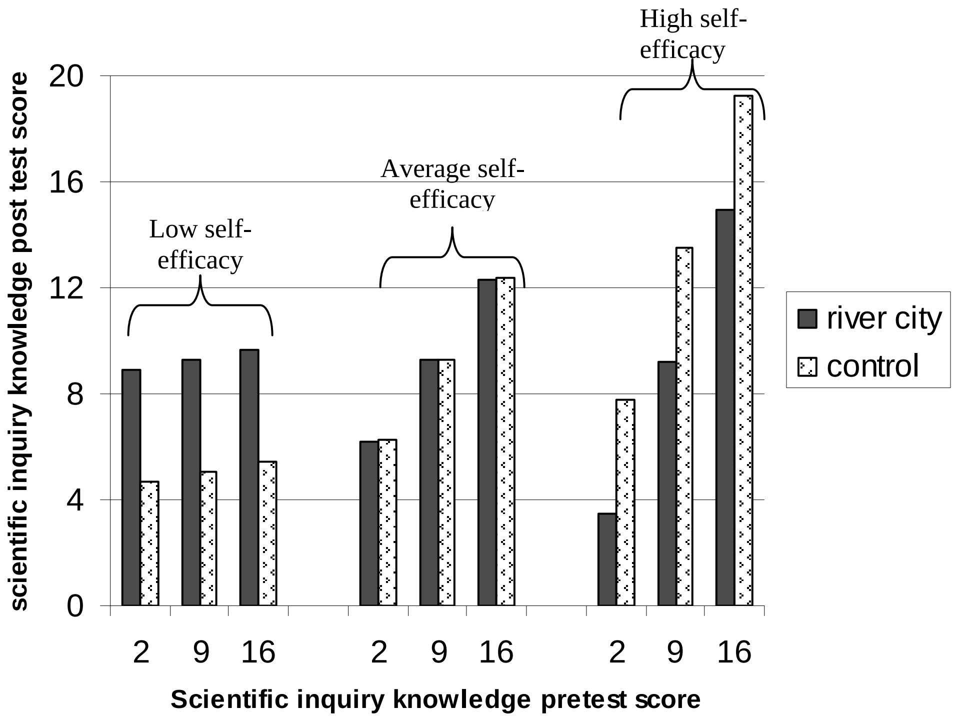

Figure 2. The effect of treatment on scientific inquiry knowledge post test score, controlling for self-efficacy and pretest score (n=93).

These results are both intriguing and surprising. We predicted that students with low self-efficacy would participate less and thus learn less than those with higher self-efficacy. However, while this is true for the control curriculum, the exact opposite is true for the MUVE curriculum with low self-efficacy students showing more improvement than their control peers. We began our research on MUVEs in an attempt to find a way to level the playing field for all students. That low self-efficacy students score nearly the same on the post test regardless of their entering knowledge indicates that MUVEs like *River City* have the potential to do just that. However, the lack of growth by high self-efficacy and by high pre-content achievers, especially given the strong growth shown by the control counterparts is troubling. While we expect that with any given pedagogical approach some students will do well and some will do poorly, these results indicate that our design needs to be modified to include alternate pedagogical strategies that engage high pre-content achievers.

Integrating MUVE curricula such as *River City* with more traditional approaches might offer different students the avenues they need to excel. However, MUVEs also have the capability to offer multiple pedagogical approaches simultaneously. For example, in order to address our findings above and explore ways to keep high achievers engaged, we recently developed an additional story line we call "Powers." This is based on the idea of videogame design where you can secretly unlock content. River City Powers is directly linked to curricular objectives. When students complete curricular goals they are teleported to a Mansion that contains information related to a previous epidemic in River City. This information is meant to be engaging and pull students into the narrative as they look at pictures and read stories about children their age who used to live in River City. We also have a crystal ball that lets them see into the future and view microscopes from different time periods. This is just one design strategy we are currently testing to see if we can keep all students engaged.

How does one student develop his conception of himself as an inquiry learner via a MUVE?

Why do low self-efficacy students under go this change illustrated above? What features of the MUVE support students' inquiry learning? Being able to solve an emerging problem in an environment where they could virtually walk around and explore helped students better understand abstract concepts such as hypothesis and procedure. Most of the students had learned about these concepts previously, however through River City they were able to "see" and experience rather than just "imagine" them (Clarke, 2006).

As mentioned above, 10 students were selected randomly and interviewed pre-post intervention. To enrich the quantitative relationships shown in the section above, we offer a case study of a typical student who prior to the curriculum had low achievement, low self-efficacy, and low motivation in science. The goal is to show this student's trajectory of participation in the MUVE and how that participation helped shape his identity as a scientist. In this particular case, Larruge (not his real name) sheds his identity as a "student failing science" and takes on the identity of a "scientist" solving a problem (Clarke, 2006).

Larruge is a 12 year old male in the 7th grade for whom English is a second language. By traditional measures, Larruge is a low-achieving student. He flunked the 7th grade and will repeat it next year. He does not think he is "good at science," has low self-efficacy, and describes the practices and activities of his science class as "boring." When asked to draw how he participates in science class, Larruge draws himself sleeping at his desk while his teacher stands in the front of the class (see Figure 3).

<u>Figure 3</u>. Larruge doing science in school

In this study, teachers were asked to rate their expectations of student participation with the *River City* project on different dimensions: behavior, engagement, and content mastery. Larruge's teacher rated him a 3 out of 5 for both content mastery and behavior and a 2 for engagement. Larruge's non-participation in science and with his teachers places him at a peripheral role in science class. Would participating in *River City* change any of that?

Generally, students spend the first day of the project getting acclimated to the virtual world and figuring out how to communicate with each other and with the *River City* residents. However, Larruge starts atypically. He enters *River City* and immediately starts organizing his teammates:

> *Larruge:* *Hey Tk2 since were team mates we need to decide where to meet so we can work together okay write back.*

On his second day in *River City*, Larruge organizes his team again and starts to engage in practices of a scientist: making observations and inferences and sharing this research with his teammates:

> *Larruge:* *Hey, I think that people are getting sick during the summer more than winter.*

Jessica: *Did you guys talk to anyone?*
Larruge: *I got it from Miss Howell*
Larruge: *Ya and*
Jessica: *What did they say*
Larruge: *She told me that people get better in the winter. It's maybe because people don't go out in the summer.*
Larruge: *So people what did you find out?*
Jessica: *I talked to Nurse Jensen she's in the hospital*
Larruge: *Ohh, what did she say*
Jessica: *She said that the people in the hospital are complaining of a bad cough*

In addition to sharing observations and inferences, Larruge and his team become curious and act on their curiosity:

Tk2: *The cook said people are really liking his food now*
Larruge: *I know I talked to him*
Larruge: *Hey so what you find out Tk2*
Jessica: *Dr. Wright said that most of the people that are sick because of insects*
Tk2: *Erica has a bad fever and her mom thinks it's from the bog*
Larruge: *Bog? Who's Erica*
Tk2: *I am going to the bog*
Larruge: *Hold on I'm going with you okay*
Larruge: *Jessica we're going to the bog*

Through his interactions with the environment and then his teammates, we see how Larruge struggles with the problem and makes sense of complexity. In the experimental world, Tk2 is confused about where the trash went, and Larruge explains what happened. Through this interaction, Larruge demonstrates his understanding of their problem solving:

Larruge: *Okay so that happened; the streets are clean and so is the river*
Tk2: *The trash goes to the sea*
Larruge: *No No*
Larruge: *Its so clean*
Tk2: *Yeah but why*
Larruge: *Because the people cleaned the city*
Tk2: *The ocean?????/*
Larruge: *No the city and because the city was clean when it [trash] doesn't go in to the water*
Larruge: *So I'm going to the hospital*

Real scientists participate within a community of scientists where they discuss and build ideas. We see this team of students participating as a community, sharing ideas and identifying ineffective strategies. In further discussion, Larruge offers an explanation and ties it back to their experiment, offering a causal reason that the trash is no longer going into the water.

Science advances through curiosity, and thus fostering scientific habits of mind involves fostering curiosity (AAAS, 1993). While there is often little room for curiosity in traditional schooling, MUVE-based environments like *River City* can foster this. Through the chat transcripts, we see that Larruge's path is often driven by his curiosity. This frames his transformation to a scientist who is engaged in inquiry. This is quite different from his pre-interview, when Larruge said he was often "bored" in science class. In the post-interview, Larruge says that *River City* was so "fun" that he did not feel like he was "in class."

> *Like, we were learning stuff without trying a lot. So, I learned what a thing was, what's it called, not an observation but..[an inference]. Yeah. It's um what you think is happening when you make an observation.*

Although he said he was "learning stuff without trying a lot," later in the post-interview, Larruge says he was "trying so hard to figure out why they were getting sick." He further elaborates that he felt like a "scientist":

> *Oh, I don't know, I guess that um the reason I liked it I guess cause you know I got to be a scientist in it. (Laughs). So, I am not really that smart either so it was kind interesting.*

While Larruge still does not think he is “smart,” he does say he felt “a little more” different about his ability to do science. Not only does he want to go to science class, but it "got students thinking" and "interested in science." "Thinking more" provided a challenge--it was not too easy—and also gave a sense of ownership for what his team "thought" about the problem.

As illustrated through his trajectory, Larruge’s participation in the valuable social practice of *River City* leads to the development of his identity as a self-directed learner (Greeno, 1997). Additionally, according to the pre-post content measures, Larruge improves his biology knowledge by 20% and his inquiry skills by 22%; his letter to the mayor receives a score of 7 out of 9. These results support what we are seeing by mapping his trajectory of participation in the *River City* project. This is the same student who, when asked to draw a picture of science class in the pre-interview, drew himself sleeping in class and stated, "I'm slow at this stuff."

Conclusions

Creating a generation of students who find science interesting and a potential career path involves re-thinking how we teach science in K-12 classrooms. MUVEs are not a panacea, nor is *River City*. However, what we have shown is that MUVEs, when designed around inquiry and science standards, have the potential to engage students in participating in the processes of science, particularly low-achieving students.

Bruce M. Alberts, chair of the National Research Council, stated in 1995, “We’ve managed to turn people off of science by making it some kind of rote learning exercise” ("Panel Urges Shift of Focus for School Science Courses," 1995). Unless we find a way to reverse this, the situation will continue to get worse. We need to explore new pedagogies, such as *River City*, to make science more accessible for all.

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