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No Magic Bullet: 3D Video Games in Education

Jason Elliott, Lori Adams, Amy Bruckman
College of Computing, Georgia Tech, Atlanta, GA, USA 30332-0280
{jlelliot, lori, asb}@cc.gatech.edu
http://www.cc.gatech.edu/elc/aquamoose/

Abstract: AquaMOOSE 3D is a graphical environment designed to support the exploration of 3D mathematical concepts. One of the underlying motivations for the AquaMOOSE project is to leverage the entertainment value of video games to provide a learning environment that engages students in more meaningful ways than are typically seen in the classroom. In this quasi-experimental comparison class study at a suburban high school, we compared the AquaMOOSE intervention to instruction using the traditional curriculum. Our results were disappointing, and call into question our underlying assumptions. In this paper, we will describe factors that contributed and discuss broader implications. Student expectations for the software were high due to the production values seen in commercial video games. In addition, the 3D aspect of the AquaMOOSE software introduced usability concerns and increased content complexity. We also encountered many classic problems of research in the classroom that affected the outcome of the study.

Introduction

AquaMOOSE 3D is a graphical environment designed to allow students to explore 3D math (Elliott and Bruckman 2002). In informal testing of the system to date, we have observed that a small number of people have an uncanny aptitude for mathematical thinking in this kind of environment. Others have an unusual degree of engagement with it, finding it quite compelling. Most do not. We began with the hypotheses that attitudes about math, spatial ability, and interest in video games would correlate with both interest in and achievement with our math-learning environment. In this comparison class study, we discovered these hypotheses to be false.

One approach to doing educational technology research is to look at current needs of teachers and students and design an intervention to meet those needs. In other words, doing "learner-centered design (LCD)" (Soloway, Guzdial et al. 1994). Had we begun the AquaMOOSE project by interviewing teachers and students, we would no doubt have learned a great deal about their needs in these areas and designed a very different sort of math learning software. However, we consciously chose a different approach. This approach to designing educational software is to look not to the users' immediate practical needs, but to try to see the bigger picture: to discover ways in which new technologies can fundamentally help create new learning opportunities. Seymour Papert writes:

> "In school math, 'analytic geometry' has become synonymous with the representation of curves by equations. As a result every educated person vaguely remembers that y=x^2 is the equation of a parabola. And although most parents have very little idea of why anyone should know this, they become indignant when their children do not. They assume that there must be a profound and objective reason known to those who better understand these things. Ironically, their mathophobia keeps most people from trying to examine those reasons more deeply and thus places them at the mercy of the self-appointed math specialists. Very few people ever suspect that the reason for what is included and what is not included in school math might be as crudely technological as the ease of production of parabolas with pencils! This is what could change most profoundly in a computer-rich world: The range of easily produced mathematical constructs will be vastly expanded." (Papert 1980)

Technology and pedagogy led us to believe there was tremendous potential to facilitate new kinds of math learning. This was our starting point. Feedback from students and teachers was regularly incorporated throughout our design process; however, we began with broader reaching goals than meeting their immediate practical needs. In this study, we attempted to combine both approaches, beginning with a more radical "bigger picture" tactic trying to harness the power of new technology to make new kinds of math content appropriable, but simultaneously trying to make this work within a traditional school context. This proved over-ambitious, as we discuss later.

Our hope for the AquaMOOSE software was that its aesthetic and entertainment appeal would motivate students who typically do not enjoy learning about mathematics. In our study at Brooks High School (BHS), this dream was not realized. Both the comparison and experimental classes learned very little about the content material, based on retention surveys given three months after the study. AquaMOOSE had little impact on what the students actually learned in the classroom.

Several important factors affected the success of our intervention. One particularly challenging issue is that the students' expectations of the software are difficult to meet. The use of 3D environments also introduces unnecessary confusion and complexity to the content material covered. In addition, we encountered several classic problems of doing research on educational technology in classrooms. These factors will be discussed in more detail below.

Background

AquaMOOSE 3D is a graphical environment designed to support free exploration of three-dimensional math concepts. Motion in AquaMOOSE can be specified mathematically, using parametric equations. For example, swimming in a sine wave in *x* and a cosine in *y* creates a spiral. Both Cartesian and polar coordinate systems are supported.

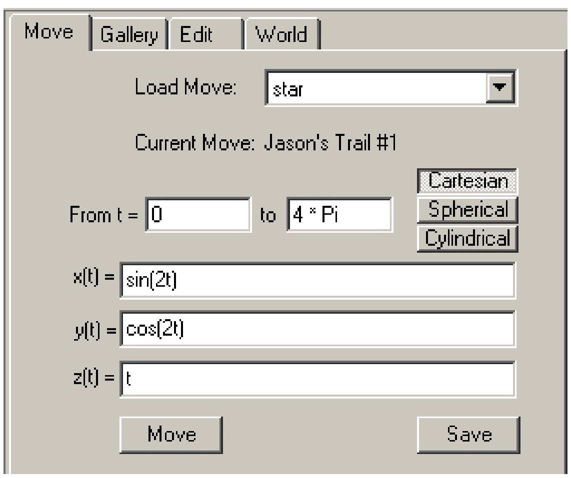

Figure 1: Math move interface

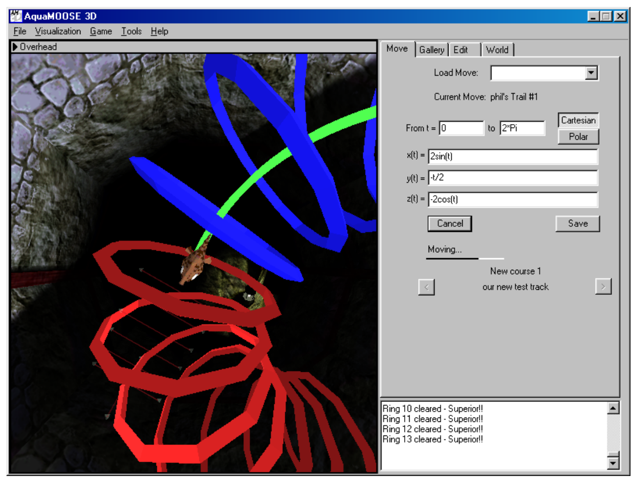

Figure 2: The ring game

A simple template scaffolds (Collins, Brown et al. 1989; Guzdial 1995) the process of entering in mathematical moves (see Figure 1). Each time a math move is executed, the avatar moves along the programmed function, leaving a trail behind. The trail is an important artifact; it provides the users with a visualization tool for instant feedback and a starting point for conversation (see Figure 3).

In many ways, this resembles the Logo programming language (Papert 1980) in three dimensions. However, there are some important differences. While the math in Logo is done from a first-person perspective to facilitate body-syntonic understanding of math (Papert 1980), the math in AquaMOOSE is designed to look more like the math students see in the classroom in order to facilitate transfer.

We also provided one prototype game for students to play in the AquaMOOSE environment: a ring game (see Figure 2). Students are presented with a set of rings in the water, and are challenged to try to swim through as many as possible with one mathematical function. This simple game resembles a 3D version of the successful Green Globs software by Sharon Dugdale (Dugdale 1982).

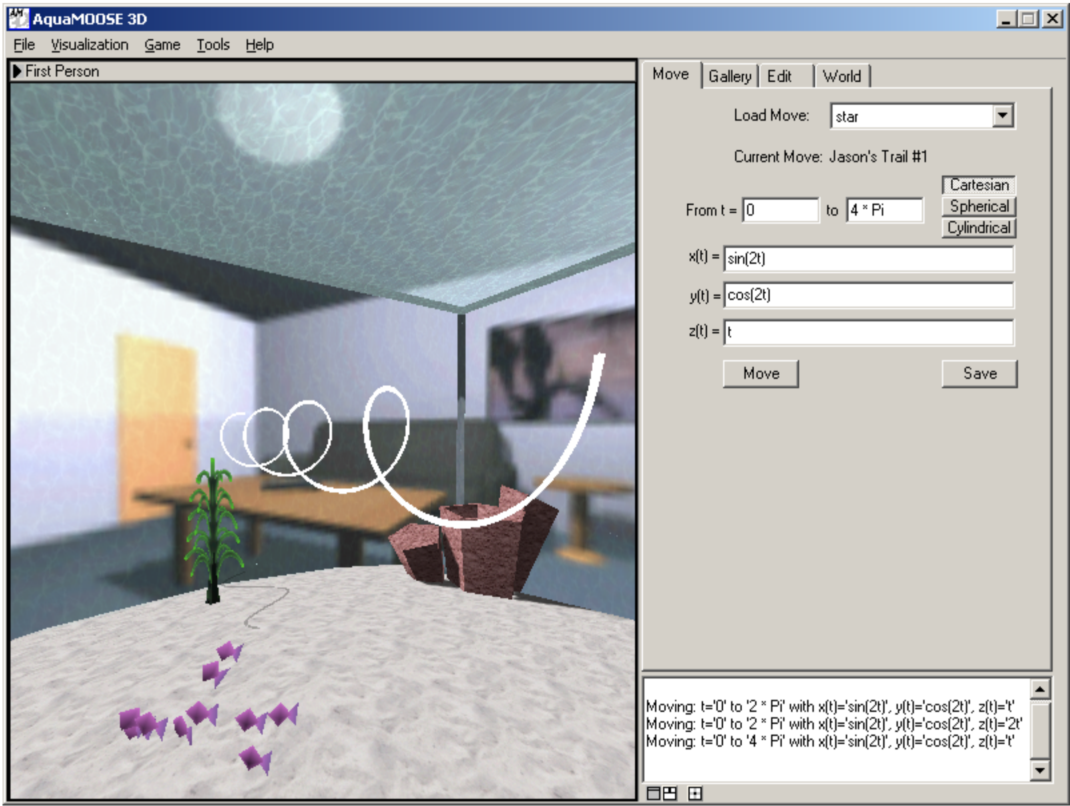

Figure 3: A trail in the AquaMOOSE environment

Study Description

BHS is a suburban public high school in central Georgia. The students at BHS are typically less advantaged and a large percentage of them receive free or reduced lunch. The teachers' expectations of the students and the students' expectations of themselves tend to be low. For example, the probable valedictorian of this year's senior class plans to go to a local community college. When asked why she would not consider a four-year college, she expressed doubt about her qualifications.

The subjects for the study came from two pre-calculus classes at BHS. The two classes were roughly the same size (N = 30 and N = 34), and met in the same classroom and computer laboratory settings for the duration of the study. The same teacher taught both of the classes.

The teacher in our study, Kimberly (1), has been at BHS for 17 years. She has seen the school demographics transition from predominantly Caucasian to predominantly African American and has dealt with the racial tension that has ensued. In several instances, her safety has been threatened on school grounds. In fact, when asked what the most challenging aspect of working at BHS was, she stated "the hallway." While she feels safe within her classroom, she has been called names, yelled at, and even choked by a student when walking around other parts of the school.

In late January, both of Kimberly's pre-calculus classes began studying polar coordinate space. This unit was taken from the county's Curriculum Guide for Advanced Algebra and Trigonometry. The comparison class for our study used the standard curriculum guide and tools while learning about polar coordinate space. The second class used the AquaMOOSE curriculum and the AquaMOOSE software in addition to the standard tools.

The Curriculum Guide states that the unit on polar coordinate space should last roughly one and a half weeks. The standard method for teaching polar coordinate space is by following Chapter 9, titled "Polar Coordinates; Vectors", in their textbook. Normal tools for the comparison class consisted of pencil and paper materials as well as hand-held graphing calculators (TI-83, TI-85, etc.). No extra software or technology was used in the comparison class.

Miller et al. note, “Learning outcomes achieved through microworld interaction depend largely on the surrounding instructional activities that structure the way students use and interact with microworlds” (Miller, Lehman et al. 1999). We developed the AquaMOOSE curriculum based on the standard curriculum found in the Curriculum Guide to help provide that structure. In addition to the standard topics, however, the AquaMOOSE curriculum included a review of trigonometric concepts, an introduction to parametric equations, an explanation of 3-dimensional functions, activities involving both cylindrical and spherical polar coordinate space, and a more unstructured lesson that focused mainly on the Ring Game portion of the AquaMOOSE software. The teacher covered parametric equations from the textbook in the comparison class to accommodate the requirements of the AquaMOOSE software.

The AquaMOOSE software was used to demonstrate various concepts during the week and a half unit on polar coordinate space. The software was tightly integrated with the AquaMOOSE curriculum. The software was available in the BHS computer lab for the duration of the study. All data from the students’ use of AquaMOOSE was logged and stored on a server at Georgia Tech.

Method

We began the study by testing the students’ visual ability and attitudes towards mathematics. We used three tests (CS-2, S-2, and VZ-2) from the Kit of Factor Referenced Cognitive Tests (Eckstrom, French et al. 1976), available through ETS, to measure the students’ visual ability. For our attitude survey, we used the Fennema-Sherman Math Attitude Scales (Fennema 1976).

The length of the study was 8 school days. Table 1 below describes the activities of the comparison and experimental classes throughout the study. The first day was devoted to administering the pre-tests of visual ability and math attitudes. The comparison class met all 8 days in their normal classroom. They also took the visual ability and attitudes tests on the first day of the study. On the eighth day, the teacher handed back the content tests and went over the students’ grades with them. We also gave the students a short questionnaire and a post-survey of their math attitudes. After completion of the unit, we conducted interviews with 3 students from the comparison class, 8 students from the experimental class, and the teacher. Three months later, at the end of the school year, we provided an open-ended survey about the content material and the math class in general.

Table 1: Study activities for comparison and experimental class.

Day	Comparison Class Activity	Experimental Class Activity
1	Pre-tests	Pre-tests
2	Classroom work	Computer lab session
3	Classroom work	Classroom work
4	Classroom work	Classroom work
5	Classroom work	Computer lab session
6	Classroom work	Computer lab session
7	Content test	Content test
8	Review of content test; post-tests	Review of content test; post-tests

Our curriculum called for the students in the experimental class to have two days of preparatory work in the classroom, followed by three sessions with our software in the computer lab. However, due to scheduling conflicts, we were only able to get two consecutive days in the lab on the fifth and sixth days of the study. The only other day that the computer lab was available was the second day of the study, before the students had any exposure to the content material. That session was used to acquaint the students with the AquaMOOSE software. The third and fourth days were spent learning some of the content material in the classroom. The fifth and sixth days were spent in the computer laboratory. The content test was given on the seventh day.

The content test consisted of three sections. The first section covered material about the basics of polar coordinate space. The second section dealt with graphing polar equations. The third section was on parametric equations and 3D graphs of polar equations. The first two sections would have been covered regardless of our study. However, AquaMOOSE required the introduction of parametric equations in addition to polar coordinate space. The teacher covered parametric equations from the textbook in the comparison class, while the experimental class learned about parametric equations mainly through the use of the AquaMOOSE software.

Our hypotheses for this study deal with a range of factors that might affect the usefulness of AquaMOOSE in the classroom, including visual ability, math attitudes, and prior experience with video games. The following is a complete description of our hypotheses.

1. Students with higher visual ability will be more likely to benefit from using the AquaMOOSE software.
2. Students' attitudes toward math and math learning will be more likely to improve in the experimental class than in the comparison class.
3. Students in the experimental class will report a more positive experience learning these topics.
4. Students in the experimental class will exhibit more motivation in post-interviews about these topics.
5. Students in the experimental class will be more likely to remember this particular unit in the end-year survey.
6. The experimental class will show an improvement in their assessment of their teacher's support for their learning.
7. There will be no changes in the teacher attitude assessment for the comparison class.
8. Students with prior video game interest and experience will benefit more from AquaMOOSE both in math achievement and attitudes.
9. Students in the experimental class who score lowest on the spatial tests may show worse math attitudes in the post-test.
10. We have no prediction whether the experimental class will perform the same, better, or worse than the comparison class with respect to polar coordinates. Benefits of the software may be offset by wasted time going to and from the computer lab, and reduced teacher control of the learning situation in the computer lab.
11. The experimental class will perform better than the comparison class on parametric equations and 3D.

Results

We used the students’ grades from the first semester of the pre-calculus class as a measure of prior mathematical achievement. The experimental class had slightly higher grades than the comparison class, but the difference was not statistically significant ($P > 0.1$).

The results from the visual ability tests did not predict benefits from the AquaMOOSE intervention on content test scores or attitudes. There were no significant changes in students’ attitudes about math during the study. The AquaMOOSE intervention had no impact on the students’ performance on the content test or on their attitudes about mathematics. Students from the comparison class scored slightly better on average than students from the experimental class on each of the three sections of the content test. However, none of the differences were statistically significant. The students who indicated prior experience with video games had higher average scores on the content test, but the difference was not significant. The AquaMOOSE intervention did not increase the advantage of having prior video game experience (the students with video game experience in the comparison class did better than the students with video game experience in the experimental class). In short, all but two (#7 and #10) of the hypotheses listed above were not supported.

While the students showed some understanding of the subject material on the content test, our retention survey at the end of the school year indicated that very few of the students remembered anything about the unit on polar coordinates. This lack of retention was true of the students in the experimental class as well as the students in the comparison class. In response to a question on the retention survey about polar coordinate space, one student in the experimental class commented, “After the test I will forget, because it’s not interesting to me.”

Four of the eight students interviewed from the experimental class did not find the use of the AquaMOOSE software helpful in learning the content material. When asked if she enjoyed using the software, one student said, "I mean, I really didn't understand it overall. It was ok. But like just to do, I wouldn't do it. Not to just have fun. I didn't think it was fun. If anything, it confused me even more." Some of the students did see benefit from using the software, but noted issues about less time on task and confusion in the computer lab.

Student responses in the survey at the end of the year were similar. Some students had a positive impression of the software. One student said that while he did not enjoy AquaMOOSE as a game, he liked being able to visualize the mathematics in a better way. Many of the students expressed negative comments about the AquaMOOSE intervention. In response to a question about his or her least favorite part of math class, another student responded, "AquaMOOSE was aweful[sic]. I didn't learn a thing, my mind just got confused and unoriented."

Discussion

Before the study began, the teacher announced to her classes that one section was going to be using the AquaMOOSE software in the computer lab, and one was going to stay in the classroom. Of course, the students in the comparison class wanted to be the ones to use the software instead. They argued that they "were good at video games" too and should get a chance to use AquaMOOSE. Those students had high expectations of the software, and thought it was unfair that they were not allowed to use it until the study was completed.

Despite this initial motivation to use AquaMOOSE, many students in the experimental class were disappointed with the software. After the study, students in the experimental class commented on the lack of action in AquaMOOSE and the imperfect models and environments that we used. One student, in response to a question about polar coordinates, said, "I don't remember anything but the ugly little fish." By telling the students beforehand that they were going to be using software that was game-like in nature, we set the AquaMOOSE software up to compete against commercial video games. As can be seen by the intense competition present in the commercial video game market, the students' high expectations are difficult to meet. For example, to create the massively multiplayer online role-playing game Asheron's Call, Turbine Entertainment had a staff of over 30 people working for 4 years (Ragaini 2000). A research prototype made by a few graduate and undergraduate students and one faculty member clearly cannot compete.

AquaMOOSE was designed to allow free exploration of 3D mathematics using primarily parametric equations and trigonometric functions. The math content of the AquaMOOSE software is very different from what is typical in high school math classes. 3D mathematics of any kind is rarely present in high school curriculum guides. The math in AquaMOOSE is not only different from anything the students had seen before, but is more difficult and is not on any of the standardized tests the students are required to take. Navigation in the 3D environment also creates confusion. Despite the use of a navigation scheme commonly seen in popular games, many students had trouble controlling their avatar's movement in the 3D setting.

Like many typical school computer labs, the lab at BHS does not readily support a classroom atmosphere. Several factors, such as broken computers, insufficient space, not enough chairs, scheduling conflicts, and the arrangement of computers into rows facing different directions, contributed to making the computer lab an unproductive setting. Several new research initiatives incorporate the use of wireless handheld devices to support learning in the classroom as an alternative to computer labs (Roschelle and Pea 2002). In reference to the problems associated with computer labs, Hickey et al. state, "that providing computer access *in the classroom* enhances the teacher's ability to use the technology-supported curriculum to support meaningful learning (Hickey, Kindfield et al. 1999)." Based on those findings, avoiding the computer lab and providing technology within the more accepted learning atmosphere of the classroom would probably increase the impact of the AquaMOOSE intervention. In addition to problems with the computer lab, there were several problems in the classroom itself. During our study, there were several times when students were called out of class to participate in required testing or other school functions. Some students were disruptive during timed tests and surveys, distracting any nearby students. The classroom was generally a hectic and often unpredictable environment.

Obviously, more time is needed for students to achieve a reasonable level of comfort and mastery with the AquaMOOSE software before attempting to build complex math creations. In our study at BHS, the students only had a couple of one-hour sessions to explore the software. Andy diSessa argues that it's unreasonable to expect computer technology to be transparent and instantly learnable (diSessa 2002). By that standard, reading and writing would also not be school appropriate. However, the standard curriculum does not usually include extra time for integrating new software tools in the classroom.

Future Directions

Based on our study at BHS, we are unable to draw conclusions about the viability of our basic goal – to create a motivating 3D graphical environment for math learning. However, we can say that creating a motivating 3D game that meaningfully enhances learning is a difficult task. One key lesson learned is that expectation management is important to a successful intervention. We introduced the AquaMOOSE software by comparing it to a video game, which led to students' high expectations. The students were expecting Quake III or Half-Life, and instead got a low-polygon fish in a freeware-rendered aquarium.

We have also gained a better understanding of our goals and design method for the AquaMOOSE project. As discussed earlier, one approach to doing educational technology research is to look at the current needs in the classroom and design an intervention to meet those needs. A second more radical approach is to look at the affordances of new technology to find ways that it makes new content appropriable. In this work, we tried to use both approaches simultaneously. We began with a radically motivated design idea. However, in our curriculum design, we tried to link our intervention to the existing curriculum, and squeezed it into a few 54-minute class periods. While our software suggests an approach to learning in which different students might learn different math content through exploration, we decided instead that we wanted to try to guarantee that all students learn a certain core of math concepts. In the final version, our actual intervention looked a whole lot like the students' regular math classes; software that was originally intended to be a catalyst for constructivist learning ended up being used in a fairly traditional way. Therefore it isn't surprising that the learning results were nearly identical for the comparison and experimental classes. So are these uninspiring results a failure of overly radical software design, overly traditional curriculum design, or the uneasy marriage between the two? Our answer is an unequivocal "all of the above."

Moving forwards, we have a three-phase plan. First, we need to incorporate feedback this trial has provided to redesign our software. In trying to shoehorn our design into a highly traditional classroom context we lost the key elusive ingredient: fun. In particular, the ring game is too hard to be fun. On the other hand, interviews and observations from our own use of the software indicate that the aesthetic properties of trails in the environment have the potential to be quite engaging. This insight will guide our redesign. Second, we plan to release the revised software free of charge on the Internet, supported by a website that allows users to trade mathematical designs they are proud of. Only when we have a thriving free-time use community will we begin our third phase, trying to further revise both our software and curriculum to make it work within a school context.

Most research projects lean strongly towards either the radical or traditional modes. We still believe that marrying these two approaches is a promising strategy. We hope this experience will prove instructive to other research teams trying to understand the delicate balances necessary.

Endnotes

(1) All participant's and school's names in this paper have been changed to protect their privacy.

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