The Virtual Solar System Project: Student Modeling of the Solar System[1]

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INTRODUCTION

Over the past decade there has been a proliferation of studies (116 studies since 1988 according to the Pfundt and Duit (1998) bibliography) reporting students' difficulties in understanding basic astronomical phenomena. For example, in the notable film A Private Universe (Pyramid Film &Video, 1988), Harvard students, faculty, and alumni were found to hold incorrect conceptions concerning the causes of the Earth's seasons, and other astronomical phenomena. In addition, Fraknoi (1994) reported that in 1988 the Public Opinion Laboratory at Northern Illinois University conducted a survey that showed only 45% of United States adults could correctly state that the Earth orbited the Sun and that it took one year to complete the trip.

As a reaction to these and other findings, numerous reform agendas have been proposed for science classrooms and curricula. The American Association for the Advancement of Science (AAAS, 1994) has called for the exploration of creative science curricula and novel teaching methodologies including collaborative student work groups, and computer-based technologies (e.g. simulations and modeling). In addition, the Division of Undergraduate Education's document, Shaping the Future: New Expectations for Undergraduate Education (1996), proposes that university faculty make a transition from traditional methods of instructing through large-class lectures to getting students involved in scientific inquiry processes instead of requiring students to complete pre-structured lab exercises.

With these reform agendas in mind we have been developing and teaching a *project based* introductory astronomy course for non-science majors over the past year and half at Indiana University, and the University of Georgia. Our course, the Virtual Solar System (VSS) shifts from the traditional large-lecture format to one in which students work in teams to construct their own models of the solar system. Specifically, students use 3-D virtual reality modeling software to create models of the solar system that they then use to investigate fundamental astronomical phenomena. Here, we describe the course and the underlying principles for its design, the core technology that makes such a course possible, the course's successes and aspects of the course that need further refinement.

PROJECT BASED LEARNING

Project based learning[1] is a comprehensive perspective that shifts away from traditional classroom practices of short, isolated, teacher centered lessons, and instead emphasizes learning activities that are long term, interdisciplinary, student-centered, integrated with real world issues that engage students in an inquiry process. Within a project-based learning environment students solve problems by developing and revising questions, formulating hypotheses, collecting and analyzing relevant information and data, articulating their ideas and findings to others, constructing artifacts (e.g. models), and participating in defining criteria and rubrics to asses their work.

Project based learning environments create a bridge between different disciplines allowing a multidisciplinary approach for the investigation of the subject matter (Blumenfeld, Soloway, Marx, Krajicik, Guzdial, & Palincsar, 1991). This is of particular importance for astronomy education because astronomy is a derivative science that calls upon the principles from several different scientific disciplines. For example, Newtonian physics provides the concepts of gravitation and electromagnetism to explain orbits, light,

[1] Project-based learning is similar to, but not to be confused with problem-based learning. See Koschmann, Kelson, Feltovich, & Barrows (1996) for a discussion of problem-based learning.

and radiation. Nuclear physics explains energy transformation in stars. Chemistry and geology explains stellar spectra and surface properties of the terrestrial planets. Lastly, mathematics is the crucial discipline that underlies all of these sciences.

For students to benefit from project based learning environments the projects must be well designed and of interest to the students (Blumenfeld, et.al., 1991). A central characteristic of well-designed projects is that there is a question or a problem, developed by the students or the instructor that drives student activities. It is imperative that these activities result in the creation of shareable artifacts or products that address the initial driving question. It is these artifacts that represent students' evolving understanding and serve as a medium through which students engage in dialogues with their peers, and in so doing reflect on and re-evaluate their emerging understandings. In the VSS course the students' construct models (i.e. artifacts) to answer the initial driving questions, and other questions that naturally arise as part of the investigation process (Barab, Hay, Squire, Barnett, Schmidt, Karrigan, & Johnson, in press)

IMPLEMENTING TECHNOLOGY

The creation of 3-D computer models has traditionally required advanced computer hardware and advanced programming skills. However, recent advances in 3-D modeling wysiwig (what you see is what you get) editors, coupled with the declining cost and growing power of personal computers has created the opportunity for students to construct complex 3-D models with relative ease. Students constructed their models using Virtual Reality Markup Language (VRML), on either Silicon Graphics computers or standard personal computers depending on the type of computers available in the computer lab. VRML is similar to HTML in that it is the standard language used for viewing Virtual Reality worlds on the World Wide Web (WWW). VRML is platform independent, object oriented, and is easily viewed over the Web using a free plug-in and a web browser. The advantage of using VRML, instead of other software packages is the ease of portability of student work to the WWW. This portability serves as a large motivating factor for the students because they are aware that their models can be viewed by their peers and critiqued by anyone who has access to the WWW. For previous student projects see the course home page at http://inkido.indiana.edu/a100/.

In the VSS course students use either CosmoWorlds from CosmoSoftware, or VRCreator from Platinum Software (which is a free product). These products reduce the tedious coding of VRML, whose structure and syntax is similar to C++, to a few mouse clicks. For example, the code to construct and texture a sphere[2] to look like the Earth is over ten lines of code in length. Instead of typing in obscure commands, one simply drags a sphere from the toolbox into the workspace and one can resize, reorient, change it's lighting and texture properties all within a short period of time (see figure 1).

[Insert Figure 1 about here]

This procedure takes the student a few seconds, freeing him or her to concentrate on learning astronomy instead of struggling to learn the syntax and structure of programming.

[2] A texture is a 2-D image that is stretched over a 3-D object in the virtual space.

COURSE CURRICULUM

Course Design

The VSS curriculum is based upon four theoretically and empirically sound principles regarding how students learn. First, we believe that if students are to learn science, they need to be actively engaged and participating in problem-solving and exploratory activities in which they can manipulate artifacts that embody astronomical concepts. Second, there must be opportunities for students to converse and communicate about their understandings with each other during these activities. Third, students need to work collaboratively in teams, because collaborative work forces students to allocate task responsibilities, design and negotiate methods and procedures for solving a problem, and evaluate their solution using the combined talents of their team. Lastly, students need to construct their own models for exploration and investigation rather than being immersed in pre-developed models that represent an expert's conceptual knowledge. When students are engaged in constructing their own models, they develop a conceptual understanding of phenomena through an iterative process of stating their own conceptual understanding, then testing their understanding by exploring the consequences of changing the parameters of their model, and finally revising their model to better match the actual phenomenon under study (Confrey & Doerr, 1994, Penner, Lehrer, & Schauble, 1998).

Course Structure

The VSS course is a freshman level course for non-science majors, first envisioned by Dr. Kenneth E. Hay, in which students work in dyads and triads to build 3-D models of different aspects of the Solar System. The course is a worth three credits and meets twice a week for two hours each day during the regular fifteen week semester. During the eight-week summer sessions the course meets four days a week for two hours each day. The course has longer contact hours than the average three-credit course, because much of the work students do related to construction of their models occurs during the regularly scheduled class time. The first week of the course primarily consists of explaining the nature of the course to the students, introduction of students to each other, choosing teams, exploration and learning of the software, pointing out resources (the course website, their textbook, other relevant WWW sites), where the students can obtain and research information regarding the solar system. At the conclusion of the first week the students are usually comfortable with the course environment and begin the construction of their astronomical models.

Project Design

The VSS course is comprised of three modeling projects of increasing sophistication designed to engage students in modeling different aspects of astronomical phenomena that are typically covered in a traditional lecture-based class. Each project begins with a set of pre-developed instructor "driving" questions that focus students on some of the major astronomy concepts to be modeled. However, as the students conduct research (reading in their textbook, WWW), and plan the design for their models, they are expected to formulate more questions, and address those questions with and through their models. To complete the curriculum the instructor, when deemed appropriate, asks additional "extension" questions that challenge student thinking and their understanding of astronomy.

The teams primarily work as a whole unit on the first project, however, by the second and third projects the students divide project responsibilities because the recognize that to construct accurate and complete models that demonstrate astronomical concepts will require the talents of every team member. Typically one to two team members focus on constructing a dynamic model (e.g. planetary orbits), while the remaining team members concern themselves with the static features of their model (e.g. planetary interiors).

In the first project the students construct a model of the Celestial Sphere (see figure 2). The Celestial Sphere is a useful concept, first envisioned by ancient astronomers, to represent the location of stars, planets, and important positions of the Sun throughout the year.

[Insert Figure 2 about here]

In this project the goals for the students are to construct a geocentric model of the Earth-Sun system to learn essential astronomical terminology (e.g. right ascension, declination, solstice), to learn the causes for the seasons, and to build a conceptual foundation upon which future astronomy concepts will be constructed. This project introduces the students the functionality of the software package, the historical development of astronomy (i.e. ancient astronomers believed the Earth to the be center of the Universe), and provides time for them to increase their comfort level with their computers. This project usually takes between three to four weeks to complete, or about six to eight class periods.

In the second project students construct a more dynamic model of the Earth-Moon-Sun system (see figure 3). The students are expected to investigate the relationships (i.e. orbital paths, periods) between these bodies. This project extends the conceptual richness of the first project because students concern themselves with the scale of the Earth-Moon-Sun system, orbital motions of the three bodies, and conditions for lunar and solar eclipses.

[Insert Figure 3 about here]

The students are asked to compare their model with the real Earth-Moon-Sun system and report on any discrepancies (e.g. scale, orbital speeds) between the two. This project also includes student-constructed models that illustrate the differences and similarities of the interior structures of the Earth, Moon, and Sun.

The third project consists of students constructing a model of the entire Solar System. Students are expected to build a model of the Solar System that takes into account the rotational and revolutional rates of the planets, and the relative sizes and distances between the planets. In constructing their models students grapple with the difficult concept of the vastness of scale of the solar system. Lastly, they are expected to investigate the similarities and differences between the planets' orbital motions, spins, interior structures, moon systems, and atmospheres.

At the conclusion of each project, the students are given a range of opportunities to reflect upon the model construction process and the astronomy concepts demonstrated through and embodied in their models. First, students present their model to the entire class and discuss the astronomy concepts featured in their model. We believe this a critical aspect of the course, because it provides a forum through which students can test their understandings against others, and creates an opportunity for students to share and show pride in their creations. Second, teams create a joint paper describing the astronomy concepts that the team modeled and any model comprises that may affect their model's behavior (e.g. using circular instead of elliptical orbits). Third, students write individual papers comparing and contrasting their projects with other student projects in the class and with the characteristics of the real solar system. Fourth, students view their models as a team in Indiana University's CAVE[3] (Computer Automated Virtual Environment). The CAVE is an 8' x 8' immersive virtual environment that allows an entire student team to explore, and discuss their models simultaneously. Lastly, each student submits an individual report to the instructor in which they report on their and their team members' contribution to the project, as well as changes they would make in the project design. These activities provide the students time to reflect on the modeling process, as well as additional opportunities to reflect on and clarify their understandings embodied in their models.

OUTCOMES AND FUTURE CHALLENGES

Overall the course has been a success. We have conducted extensive interviews with students before and after each course to gauge their astronomical understanding, and the results indicate that the students' conceptual understanding grew as a result of taking the course (Keating, Barnett, & Barab, 1999). For additional work related to learning outcomes and critical analyses of the course and its development see http://inkido.indiana.edu/mikeb/publications/.

The students also expressed a great deal of satisfaction with the course that can be summed up by the following student comment:

[3] See http://www.ncsa.uiuc.edu/VR/Docs/CAVE_Current/CAVEGuide.html#description for a more in depth description.

> "This was the best science course I have taken. I had fun, while I learned about astronomy. Astronomy has always been interesting to me, but I didn't want to sit and be lectured to. This class was perfect for me."

As with any experiment, some difficulties emerged as we taught the course. The major problem was with the functionality of the VRML software. The currently available software, while easy to use, does not permit investigation of some basic astronomical phenomena such as the changing of the Sun's incident light on the Earth, the ability to include and change gravitational forces, construct elliptical orbits, and a freeze time feature to study interesting interactions (i.e. when an eclipse is occurring). To eliminate these difficulties, Dr. Ken Hay at the University of Georgia is developing a software package that allows students to implement the aforementioned astronomical phenomena. A test of the prototype software was conducted with a class at the University of Georgia this past summer term, and the preliminary results are most promising.

One of the major challenges for the future viability of the course is scalability. The first two courses, taught in the spring and summer terms of 1998 consisted of only eight students. Then, after further refinement, we taught two sections in the spring term of 1999, consisting of fifteen and seventeen students. However, even with these increased numbers, there is still a sizable discrepancy between the VSS course size and a traditional introductory astronomy class taught at Indiana University. However, for smaller colleges and universities where enrollment in introductory astronomy courses is not so overwhelming we believe that the VSS course could be an effective alternative to current instructional approaches. Nevertheless, we are investigating various options of implementing the VSS course in diverse settings with a larger number of students.

DISCUSSION

In the VSS course students are constructing models of the solar system in an inquiry process while learning about fundamental astronomical questions. Central to the design of the course was our pedagogical commitment, which involved moving away from lectures and toward immersing students within a learning environment that they actively participate and engage in processes associated with scientific investigations. Our findings indicate that this approach holds great potential in facilitating student learning of astronomy through the construction of models. As we continue to do research, and refine the course we will gain a richer understanding of the potential that the VSS course has not only for astronomy education, but for other science courses as well.

REFERENCES

Barab, S., A., Hay, K. E., Squire, K., Barnett, M., Schmidt, R. Karrigan, K., & Johnson, C. (in press). Virtual Solar System Project: Developing Scientific Understanding Through Model Building. To appear in the Journal of Science Education and Technology.

Confrey, J., & Doerr, H. M. (1994). Student modelers. Interactive Learning Environments. 4, 199-217.

Fraknoi, Andrew (1996). The state of astronomy education in the U.S. In J. Percy (Ed.), Astronomy education: Current developments, future coordination (pp. 9-25). Astronomical Society of the Pacific: San Franciso, CA.

Koshmann, T., Kelson, A. C., Feltovich, P. J., & Barrows, H. S. (1996). Computer-supported problem-based learning: A principled approach to the use of computers in collaborative learning. In T. Koshmnan (Ed.), CSCL: Theory and Practice of an Emerging Paradigm (pp 83–124). Lawrence Erlbaum: Mahwah, New Jersey.

National Science Foundation. (1996). Shaping the Future: New Expectations for Undergraduate Education (No. NSF96-139). Washington D. C.: Author.

Penner D. E., Lehrer, R., & Schauble, L. (1998). From physical models to biomechanics: A design-based modeling approach. The Journal of the Learning Sciences, 7, 429-449.

Pfundt, H., & Duit, R. (1998). Students' Alternative Frameworks and Science Education. Bibliography. 5th ed. Kiel Univ. (West Germany). Institut fuer die Paedagogik der Naturwissenschaften.

Pyramid Film & Video. (1988). A private universe. An insightful lesson on how we learn [Film]. Santa Monica: CA.

Figure 1: Student creating an Earth with a 23.5 degree tilt using VRCreator.

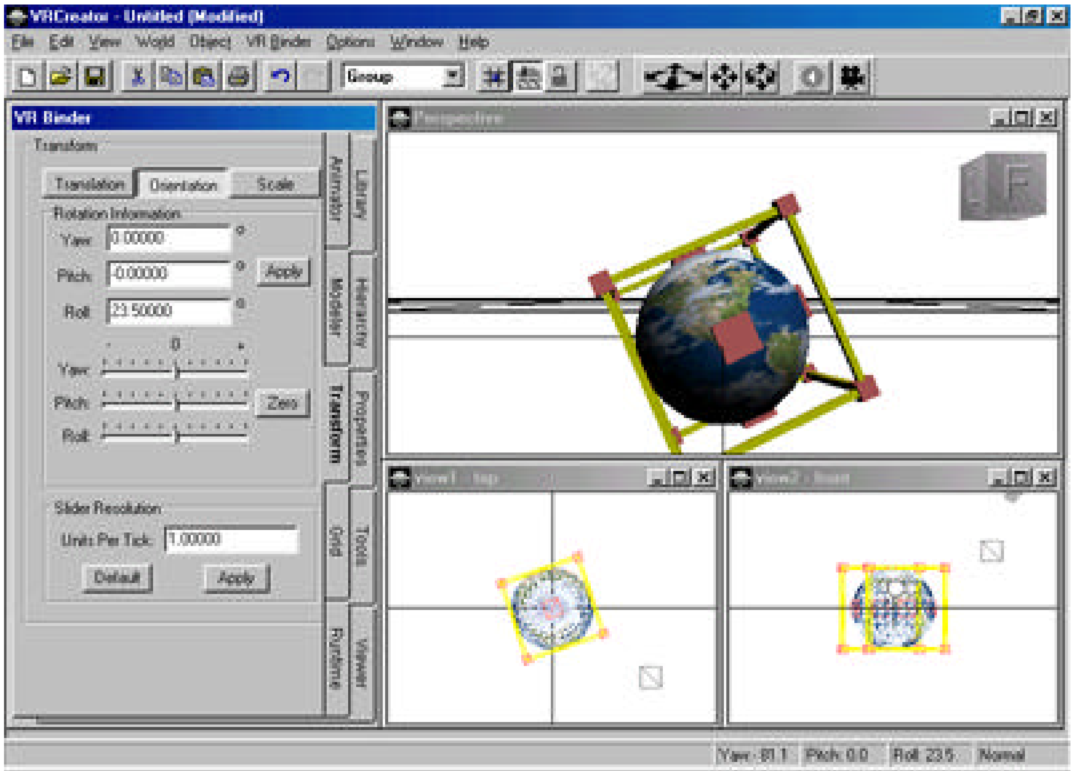

Figure 2: Student exploring their constructed model of the Celestial Sphere in Indiana University's CAVE. In this model the students show the locations of the solstices and equinoxes as well as the path the Sun traverses during the course of a year.

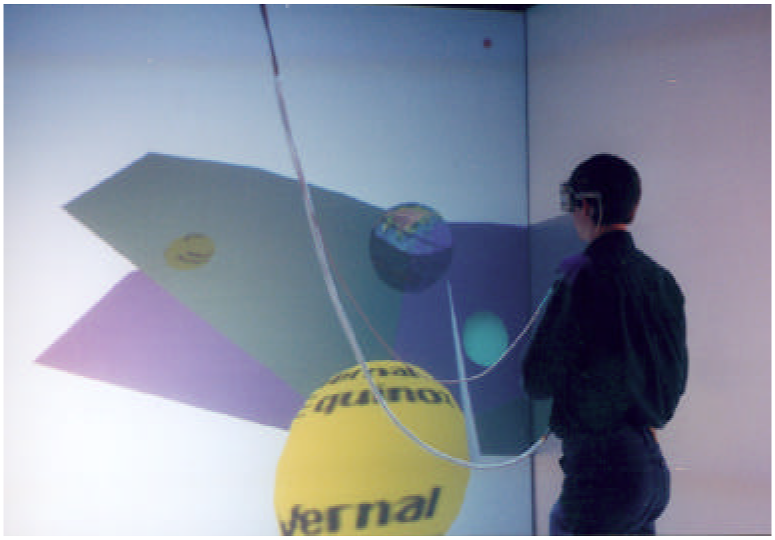

Figure 3: A student teams' model of the Earth-Moon-Sun system. In this model they are demonstrating the shadow cast by the Earth.