C. PROJECT DESCRIPTION

I. Results of Prior NSF Support

Title: A Shared Developmental Environment for Science-Based Courseware. Phil McClean, P.I. Source of Support: NSF Division of Undergraduate Education. Amount: $155,000 (Project Number DUE-9752548). Start date: February 1, 1998. Two years.

This project is a collaboration among faculty in the Departments of Computer Science, Biology/Botany, Plant Sciences, and Geosciences at NDSU to construct several interactive science education software components: the Virtual Cell project; the Visual (computer) Program project, and the development of the text-based version of the Geology Explorer. The goal is to develop strategies for the construction of multiuser virtual learning environments that are common across diverse scientific disciplines. Research has also focused on the development of software tools to assist in the construction of interactive virtual learning environments, and on implementing prototypes in classroom settings. Examples of the tools developed to date include an abstraction hierarchy building tool, an environmental effects tool, a conversational construction tool, a map building tool, and others.

All three of the projects have been fielded in courses at NDSU. A Virtual Reality Modeling Language (VRML) prototype of the Virtual Cell has been completed, with the first educational module pilot tested in an introductory cell biology class in March 1999. The Visual Program project implemented a range of VRML simulations of program execution during Fall 1998 and is embarking on a plan for measuring their effect on classroom instruction during Fall 1999. The text-based Geology Explorer was tested in a small section (25 students) of Physical Geology in Summer, 1998, and then in a large section (over 400 students) of the same course in Fall, 1998. Impact on student learning in the large section course was measured using methods described in the body of this proposal; analysis of the data indicate a significant improvement in abilities of those students who experienced the Geology Explorer to think conceptually about geologic concepts and to address geologic problem-solving scenarios. A comprehensive web site detailing development of these projects is available at http://www.ndsu.nodak.edu/wwwic/.

Title: Learning by Doing Physical Geology in Virtual Laboratory / Virtual Field Trip Computer Environment. Brian M. Slator, P.I. Source of Support: NSF Directorate for Geosciences. Amount: $49,981 (Project Number EAR-9809761). Start date: October 1, 1998. One year.

This project is a collaboration between the Departments of Computer Science and Geosciences at NDSU to implement an interactive graphical user interface (GUI) to the Geology Explorer. The present text-based version uses a command-line interface. However, because geology is highly visual science, we believe a GUI will provide spatial authenticity, easier navigation, and engaging visualization of geologic objects, contexts, and processes in the synthetic environment. Using virtual tools, the student will sample, test and identify minerals and rocks while navigating geologic landscapes that are graphically rendered. About 75% of the necessary rendered landscape images, instruments, objects, icons and detail images have been created for the prototype java-based GUI which is accessed through a standard web browser.

A web site providing details of both the text-based and graphical-based versions of the Geology Explorer, and where you can play the text-based version yourself, is available at: http://oit.cs.ndsu.nodak.edu/.

Proposal: New Directions in Virtual Geoscience Education

II. Project Overview: Science Education on Planet Oit

The goal of our research is to evaluate the use of active synthetic environments on student learning of scientific problem-solving skills such as those that would be learned on a "real" field trip. The objective of this project is to produce a software product to be distributed nationally. With this distribution we propose to both teach current curriculum better, and add curriculum not taught before.

This project is being undertaken by a collaboration between the Department of Computer Science and the Department of Geoscience at North Dakota State University, in cooperation with teachers at a four-year college, Minot State University (Minot, ND), a two-year college, North Dakota State College of Science (Wahpeton, ND), and Discovery Junior High School (Fargo, ND).

To achieve these goals, we have constructed a highly interactive environment that provides "live" simulations for exploration and discovery that engage learners while treating them to a plausible synthetic experience. Within this context, the student makes decisions similar to those of a geologist, using simulated tools and the techniques of geoscience. We have implemented the first prototype of such an experience to teach in a "learn by doing" manner the fundamentals of geology, the Scientific Method, and the strategies of deductive problem solving (Saini-Eidukat et al. 1998, 1999; Schwert et al. 1999; Slator et al. 1998, 1999).

The Geology Explorer is designed to give students an authentic experience that includes elements of a) exploration of a spatially oriented virtual world, b) practical, field oriented, expedition planning and decision making, and c) scientific problem solving (i.e. a "hands on" approach to the scientific method). We have named this particular experience “Planet Oit.” The objectives of the project include assessment of student performance, evaluation of instructor feedback, and incorporation of that information into the continuing design of the synthetic world. The larger objective is the distribution of this experience to earth science and geology students around the world.

Building on the Geology Explorer proof of concept, we propose to move in two new directions: 1) exploration of active geologic processes, and 2) the study of the structure and composition of inaccessible parts of the bulk Earth (as simulated on Planet Oit). Currently, students learn deductive reasoning by performing experiments in the synthetic “field.” What has not been possible to date, however, is for students to make measurements of active processes such as flowing streams, or volcanic gas exhalations, and then to use this data to make testable hypotheses. Implementation of such activities will necessitate the construction of detailed robust scenarios. The second new direction responds to the difficulty most students have in grasping concepts associated with geology that is physically unreachable. It is obviously impossible for students to pass through a planet's crust and measure the physical-chemical properties of the mantle and core. However, in a synthetic environment the student can enter the inside of a planet, acting as a geologist might, and can evaluate credible geologic situations using synthetic measuring devices to collect and evaluate data. These types of scientific activities are simply not done in Physical Geology courses; we believe the Geology Explorer will be an excellent tool to engage students in learning this aspect of Earth Science.

III. Project Goals and Objectives: The Third Dimension

One of the principal goals of science education is to teach students a framework of basic principles and approaches that can be used to solve science-based problems. In addition, every scientific discipline is content-based. For students to have a successful appreciation of the sciences, they must master both the framework of science and the content of individual disciplines. One major challenge for science educators is to develop educational tools and methods that deliver the principles but also teach important content material in a meaningful way. At the same time, the need for computer-based education and distance learning systems has become increasingly obvious, while the value of "active" versus "passive" learning has become increasingly clear (Reid, 1994).

Teaching science using a “learn-by-doing” philosophy is not new (Dewey, 1900), but its applications using the modern tools of virtual reality is only now becoming an actuality. Students can now take on the role of scientists in virtual worlds that provide access to environments that are difficult or impossible to visit in the real world: distant worlds, subatomic spaces, or dangerous places. They can hypothesize, carry out experiments, evaluate data, and make scientific conclusions, in short, learn the scientific method in new and stimulating ways.

We propose an approach to computer-based media for science education resting on the metaphor of a spatially oriented "virtual place." Our approach is in the context of an educational game that emphasizes active rather than passive learning. In particular, we propose to complete development and commercially release an educational game, The Geology Explorer, to teach in a "learn by doing" manner the fundamentals of the geology, the Scientific Method, and the strategies of deductive problem solving.

IV. Project Plan

As an example of the kind of course we propose, Physical Geology (NDSU Geology 120) is a large-enrollment (>400 students/section), 3 semester hour lecture course. Aside from lecture, the course content is augmented by slides, by a set of course lecture templates, by a textbook, and by a web resource site which includes self-quizzes, photographs, course news, and links to related resources http://www.ndsu.nodak.edu/instruct/schwert/geosci/g120/. Testing is by multiple choice exams, with students submitting their results on optical scan sheets. Nearly 100% of the students enroll in the course to complete either general education requirements or specific course requirements within their majors. In a typical course, of the approximately 440 students enrolled, at most 2 or 3 are Geology majors.

1. Prototype Implementation

While it would be ideal for each student enrolled in Physical Geology to participate in a field trip to, say, the Black Hills of South Dakota to "learn by doing" geology in a natural setting, it is logistically and financially impractical to do so. The Geology Explorer is a multi-modal virtual environment undergoing a phased implementation employed to maximize development with finite resources. The first module involves mineral exploration, where students are expected to plan an expedition, locate and assess potential mineral and ore deposits, and survive to report on it.

The first step was to write a storyboard for the project which directed the development of the synthetic Planet Oit. A map was drawn to show the different environments on the planet (for example, Brown Dunes) and what will be encountered when the student travels southeast (the Red Beach), or south (the Lake Region). A group of summer school students originally implemented multiple locations from which the geological expedition could begin. Geological tools were developed (such as streak plates, hammers, and Geiger counters), and the appearance and response of 40 minerals and 40 rocks to a series of interactions were simulated.

The Geology Explorer project has two modalities: a text-based mode, where Planet Oit is primarily defined in terms of its Geoscience structure; and a graphical mode, where the existing functionality is visually enhanced with landscapes, instruments, and other images.

Planet Oit is simulated on a MOO ("MUD, Object-Oriented," where MUD stands for "Multi-User Domain"). MUDs are typically text-based electronic meeting places where players build societies and fantasy environments, and interact with each other (Curtis 1992). Technically, a MUD is a multi-user database and messaging system. The basic components are "rooms" with "exits," "containers" and "players." MUDs support the object management and inter-player messaging that is required for multi-player games, and at the same time they provide a programming language for writing the simulation and customizing the MUD.

We have implemented the Geology Explorer as a synthetic environment using the freely available Xerox PARC LambdaMOO, which is a development environment for creating text-based virtual worlds, to simulate a portion of Planet Oit (very similar to Earth, and in the same orbit, but directly opposite the Sun). Because the Geology Explorer project is intended to be a platform-independent distance education system, the Internet client software for the project is developed in Java and accessed with browsing software.

The development of Planet Oit began with a realistic planetary design which included roughly 50 locations (arroyo, mesa, desert region, etc.), and over 200 boulders, veins, and outcrops; each implemented as simulated software objects. Once the layout and artifacts of Planet Oit had been implemented, the "rules of the game" were laid on top. In particular, we have built an environment where students are transported to the planet's surface and acquire a standard set of field instruments. Students are issued an "electronic log book" to record their findings and, most importantly, are assigned an exploratory goal. These goals are intended to motivate the students to view their surroundings with a critical eye, as a geologist would. Goals are assigned from a principled set, in order to leverage these role-based elements of the game.

An on-line rock and mineral resource is being developed to allow students access to common reference materials. A simple on-line tutorial is also under development. Finally, a tracking mechanism follows students through the course of their explorations, to identify how they are using the technology, and to implement software tutors (described below).

Students "land" on the planet to undertake an exploration exercise armed with tools and instruments implemented as LambdaMOO objects. They are given an authentic geologic goal, e.g., to locate and report the position of potentially valuable mineral deposits. Accomplishing these goals entails mastering several geologic concepts and procedures, and demonstrates student mastery of the material. The students make their field observations, conduct small experiments, take note of the environment, and generally act like geologists as they work towards their goal of, say, locating a kimberlite deposit. A scoring system has been developed, so students can compete with each other and with themselves.

Simultaneously, we are implementing a highly interactive and highly graphical user interface (GUI) to the game. There are four reasons for moving in this direction:

1) In the text-based version, navigation, location, testing, and identification all require students to learn a command syntax. While this syntax is not difficult (a simple, three-fold user's guide is provided each player), it nonetheless slows the game-playing experience — and hence the learning opportunity. Nearly all students entering college today have had prior experience in playing with graphically-based computer or video games and are comfortable in that mode. In the GUI, instead of a student typing in a command syntax to pour acid on a specimen, the student simply uses a mouse to move the acid bottle from the tool pouch onto the specimen itself. A bubbling visual display, accompanied by sound, confirms the validity of the test.

2) Planet Oit is a geographic entity, wherein one can now navigate in two dimensional space (and, soon, three-dimensional space). Using the GUI, the player will navigate the planet smoothly with a computer mouse and in the realm of any 360° angle viewing

both the continuum and transition of physiographic environments. In the text-based game, however, the player uses a rather-limiting command language ("north," "northeast," "west," etc.) to jump from space to space, experiencing neither the continuum nor transition of environments.

3) Mineral and rock identification in the text-based game requires the game to provide the player with efficient but effective written description of the specimen and its characteristics. In the GUI this problem is addressed by providing highly-quality projections of 1X (hand specimen) and 10X (hand lens) jpeg images as the student encounters and tests specimens.

4) The graphical interface will better reinforce "visual" concepts taught in lecture. Instead of reading the word "dike," students will see dikes. Instead of imagining what quality of reflection is induced by "resinous luster," students will see this luster.

A key element of the exploratory game idea is the notion of a spatially oriented synthetic environment where learners explore and discover. The Spatial Metaphor maps a domain (and, consequently, its interface) onto the basic spatial elements on Planet Oit. The Java/MOO visual component of the Geology Explorer accomplishes this using client software written in Java that is a viewport into the MOO running the game server. In it, objects are represented by graphical elements that can be manipulated in a way that makes sense to the domain. We have developed a Java client and communication protocol to support the viewport — an accurate and consistent representation of the data on the game server. Changes in the server are reflected in the viewport, and manipulations of the viewport change the state of the server. The viewport on the client machines is a view in a window that displays pictures representing such MOO objects as exits, objects, and other players.

The viewport is responsible for storing the current room information, storing a list of objects in that room, notifying those objects when their state changes, and notifying the server when the user manipulates the objects. The viewport is used mostly for protocol between the server and the objects in the room, and also between the objects and the platform's user interface routines.

For the new research experiences to become integrated into the GUI, we will need to significantly extend on the work done to date. Specifically, graphical methods for students to acquire and analyze data will need to be developed. The scale of the simulation will need to be appropriate to the problem of interest; for example in the stream velocity example (below), several reaches of the stream will need to be represented and cross-sectional plots and data-graphing utilities will need to be incorporated into the interface.

2. Text-Based Planet

Planet Oit development has been accomplished by creating objects in the LambdaMOO environment and implementing methods (verbs) on those objects in order to simulate an authentic exploration and problem-solving experience. Planet Oit is built out of an "entryway room" which represents the expedition's landing and staging area, with exits leading toward each of the compass directions. There are seven main areas adjacent to the Planet Oit entryway:

1. To the north is a glistening, azure, ocean seashore
2. To the northwest you see a sparkling inland lake
3. To the west is a majestic range of chiseled mountains
4. To the southwest you see a vast expanse of open prairie
5. To the south is a blistering desert
6. To the east is the soft outline of a mountain range, and
7. To the northeast you see a broad area of rolling hills and valleys

On Planet Oit, every exit must have a direction as one of its names (e.g. "East"), and a letter-direction name (e.g., "e"), and a room-direction name (e.g., "cave"). Therefore, a player in the Old Mountains can type "n", or "north", or "cave" and get to the "cave with stalactites."

Rocks and minerals on Oit are implemented as objects of type $thing. Each object is further defined with properties for: rock type (igneous, sedimentary, or metamorphic), movability, odor, flavor, texture, density, height, weight, depth, color, luster, magnetism, hardness, chemical composition, and others. Once objects for rocks and minerals were defined, verbs were written to describe each rock's behavior when they react with the geologist's instruments. For example, verbs to react to "hitting" (with a hammer or rock pick), and for "pouring" (a 10% solution of Hydrochloric Acid), were specified as follows.

The player will say: *hit object with instrument.* The instrument defines a "hit" verb, which produces a message and then calls a verb as follows: object*:hit_by(instrument)* The rock or mineral defines the appropriate hit_by behavior to handle the following cases:

- *chip* : a message that chips are flying
- *split* : a message, and create a movable child (appropriately sized, etc.) of the rock
- *destroy*: a message and recycle the rock
- *nothing*: a message that nothing happened.

What happens when other things (i.e. the compass or the gravimeter) are used to hit a rock? These verbs are mostly short and consisting of two things:

1) messages describing the actions of an instrument in terms of sight and sound; and

2) a "message" sent to, or a verb invoked on, the object of the instrument's action. For example, the hockey stick (implemented for comic effect), makes a "whooshing noise". Then it calls the hit_by verb on the relevant object.

You can see an annotated transcript of Planet Oit by visiting:

http://www.cs.ndsu.nodak.edu/~slator/html/PLANET/transcript2.html

3. Graphical Planet

Through development of the Geology Explorer, we have successfully implemented a synthetic surface environment for learning the logic of mineral and rock identification. In the proposed new simulation, two types of active research questions will be implemented for students to explore. The first type allows students to investigate a plausible goal which is impossible in the real world, for example, to locate and report the location of diamond at its source in the mantle. At the beginning of their journey, students will choose an authentic research question and will acquire special virtual tools to allow them to measure chemical composition, viscosity, density, seismic velocity, and other parameters as they move through the bulk of the planet. They will make "field" observations, conduct experiments, and generally behave as a geologist would if it were possible to, for example, stand on a subducting tectonic slab, or on the outer core/inner core boundary. By accomplishing the goals implied by their research question, the students will have demonstrated mastery of several important geologic concepts and procedures, and therefore mastery of the material. In this new exploration direction (namely, down), students will be presented with questions such as:

1) What is the minimum and maximum depth at which diamonds are found in the mantle. Is there lateral variation in their abundance? If so, why? (For example, could there be a relation between age of overlying crust and abundance of diamond?)
2) Where do mantle plumes originate, and how can we determine this?
3) Are there variations in viscosity and seismic velocities of the upper mantle? What are the planet-scale implications of zones of low seismic velocity?
4) By making measurements or observations with a "crystal structure microscope," where do mineral structure changes occur inside the planet? What do these changes mean for variation of seismic wave velocities?
5) After predicting the density and composition of the planet's core, use an "instant chemical analysis tool" to determine the amounts of major and trace elements in the core. How can these data be reconciled with density measurements?
6) How are measured variations in isotope ratios of elements such as Rb, Sr, Nd, U and Pb used to determine source or age of mantle or crust?

To assist in answering these research questions, a new set of virtual instruments will be constructed (using discrete simulation), some of which are not technologically available in the real world but can be available in the virtual world:

1) Seismic velocity instrument: Directly reads relative velocities of P and S waves at all positions within the planet, both within and between the layers.

2) Specific gravity instrument: Directly reads densities of compositional materials at all levels within the planet.

3) Gravity instrument: A gravimeter especially useful to the student when exploring variable properties of the lithosphere.

4) Temperature instrument: A thermometer that directly measures temperatures at all levels within the planet.

5) Pressure instrument: Directly reads pressures at all depths within the planet (student can also interplay with role of pressure in melting).

6) Chemical composition instrument: Directly presents to the student the compositions of all materials sampled within the planet (student can also interplay with the role of water in melting); will provide major and trace element composition.

7) Viscosity instrument: A highly theoretical instrument that presents the student with information on material states.

8) Magnifying instrument: An unusual microscope that will provide the three-dimensional crystal structure of phases upon which it is trained

9) Mass Spectrometer: Instantaneously provides isotopic composition for age dating or source region analysis.

At any (virtual) location inside the planet, all relevant bulk physical and chemical properties for samples will be available for measurement by the student.

The second type of research topic will involve active investigation of processes. An example is investigation of the cross-sectional and velocity profile of a meandering stream. In an exploratory exercise, the student visits sites along a meandering stream on the planet. The cross-sectional profile of the selected site is presented to the student, who then uses a virtual velocity meter to plot isolines of uniform velocity for the profile. The student compares the available velocities within the profile to velocities charted for entrainment and deposition of various particle sizes on a standard diagram and makes a prediction as to what the consequence on the particle will be (i.e. entrainment/transport or deposition). The student drags sediment particles of various size onto the profile to test the validity of his/her hypotheses. Questions explored in this research topic include:

1) For any particular cross-section of a meandering stream, what are the relative velocities of flowing water across the profile?
2) How do the cross-sectional and velocity profiles change as one passes up- or downstream along the meandering stream course. Why?
3)What velocity zones of any cross-sectional profile are sufficient to entrain and transport particles of clay, of silt, of sand, of fine gravel, etc. What is the impact of this on profile/stream course change through time?
4) In what velocity zones of any particular cross-sectional profile will already-entrained sediment particles of a particular size become redeposited? What is the impact of this on profile/stream course change through time?

Other examples of this type of research topic include: measurement of earthquake waves and prediction of the epicenter location, and measurement of variations in volcanic gas composition and relation to eruption frequency. To be included are:

1) Three-dimensional relationships of deformed rock bodies: Measurements of strike and dip leading to recognition and evaluation of such features as folds and joints, and the stresses under which they formed.
2) Velocity profiles across a stream: Students will evaluate the factors leading to their differential measurements of velocity within a stream's cross-section and then estimate discharge.
3) Gravity and Magnetic Fields: Using virtual magnetometers and gravimeters, students will be able to measure surface profiles and interpret the presence of subsurface rock bodies.
4) Paleomagnetism: After analyzing the present magnetic field of the planet, students will undertake measurements of the paleomagnetic record from various rock localities to address questions involving the planet's tectonic history.

5) Aquifer yield: Pump tests associated with data on an aquifer's porosity and permeability will be utilized by students to evaluate the planet's groundwater resources.

These research experiences are different than learning typical Physical Geology concepts in a new way, rather, they facilitate student learning of new aspects of the curriculum that are currently not covered.

4. Tutoring

A key feature of our educational media is the ability to tutor students. On Planet Oit, tutoring is done through unintrusive but proactive software agents. Agents monitor student actions and "visit" a student when the need arises. Tutors give advice, but they do not mandate or insist on student actions, nor do they block or prevent student actions.

Deductive Tutors provide assistance to players in the course of their deductive reasoning within the scientific problem solving required to accomplish their goals. In the Geology Explorer, the tutors work from knowledge of the rocks and minerals, knowledge of the "experiments" needed to confirm or deny the identity of a rock or mineral, and the student's history. The system encodes the necessary and sufficient experiments for each rock and mineral, as well as their expected results. The tutors check these facts against the student's history whenever the student "guesses" a deposit's identity. Tutors remediate, as appropriate.

There are currently three types of tutoring agent in the game, and plans for a fourth.

- The equipment tutor detects when a student has failed to acquire equipment necessary to achieving their goals. If the student needs certain instruments to perform necessary tests, the tutor remediates on that topic.
- The exploration tutor detects when a student has overlooked a goal in their travels. The tutor checks whether the student is leaving a location that might satisfy a goal; i.e. if their goal is to locate kimberlite, and there is kimberlite in the place they are leaving, the tutor visits the player to inform them.

• The science tutor detects when a student makes a mistake in identifying rocks and minerals; either when a student make a wrong guess and why (i.e. what evidence they are lacking); or when a student makes a correct guess with insufficient evidence (i.e. a lucky guess).

• The laboratory assistant will be very important to our plans to introduce advanced laboratory instruments into the game. The assistant will detect when a student needs help with operating a virtual instrument. By employing a "fading" strategy, the assistant will initially operate the equipment for the student, explaining what is happening, and later will prompt the student through the course of running their own analyses.

5. Faculty Development

Pedagogically, the exploratory environments of the Geology Explorer allow instructors to extend learning beyond presentation of content into the fundamental operations of science: observation, prediction, sampling, experimentation, development and testing of hypotheses, and explanation.

How will instructors react to the integration of this technology in their classrooms? To evaluate this, we have initiated a protocol for Fall, 1999, to test integration of the Geology Explorer in classrooms external to those of NDSU. Evaluations include testing at a four-year institution (Minot State University), a two-year institution (North Dakota State College of Science) and a junior high school (Discovery Junior High, Fargo) — collectively, audiences involving hundreds of students. Aside from collecting assessment data from these students, we will be receiving extensive instructor feedback that will be applied in product development, curriculum design, and the future training of instructors in the best applications of this software in their respective curricula. These initial evaluations are supported in part by higher education reform funds assigned to the Geology Explorer project through the NDSU-CoMSTEP (NDSU Collaborative for Mathematics and Science Teacher Preparation), funded by NSF.

In partnership with the instructors at the test institutions, we are investigating ways to enhance abilities of faculty to adapt their courses so as to incorporate this new type of exploratory software into their own courses. As the testing group grows, short workshops will be hosted to work with the introduction of software to new faculty.

6. Plan of Work

The purpose of phased implementation is to capitalize on the relative simplicity of text-based development. Using text, a complex visual scene can be described in just a few sentences. The graphically equivalent scene takes hours or even days of development time. Therefore, as a development strategy, first implementing in text minimizes the cost of design mis-steps. If a portion of the simulation needs to be re-done, it is much less expensive (and less painful) to revise or even throw away text descriptions. The analogous exercise, revising or scrapping a graphical user interface, is an order of magnitude more costly. In this way we guard against the common problem of making early decisions and then being "stuck" with them in some sense.

The purpose of multi-modal development is to retain consistency across versions. In what has been described, both the textual and the graphical version of Planet Oit are implemented with different client software **connecting to the same server**. By layering the simulations in this manner, we gain considerable leverage in terms of shared development and staged implementation. The model we follow, then, is one where innovations are developed in the text-based world and the graphical world follows behind, only implementing those elements that have been tested in the text-based environment.

Prior to Year One, the first text-based prototype will be completed and ready for dissemination. This module will contain fully implemented rocks, minerals, and locations, as well as software tutors for navigation, equipment, and mineral identification. We will also, by this time, have conducted the first workshop with teachers from Minot State University culminating in a pilot study of the Geology Explorer by faculty not a part of our core research group. In addition, we will have conducted a second major study with students in Physical Geology 120 at NDSU (> 400 students), and there will be a formalized report in hand detailing the findings.

Year 1

In year one, we will embark on the following course, which will remain consistent throughout the life of the project. Work will begin under five headings, with a sixth added starting in year two.

1) Studies and Evaluations: with data collected at Minot State and NDSU in Fall of 1999
2) Workshops: to familiarize our collaborators at the North Dakota College of Science (Wahpeton, ND), and Discovery Junior High School (Fargo, ND)
3) GUI Design and Development: implementation of interface modules for navigation, experimentation, reporting, etc.
4) Module Design and Development: implementation of modules for Stream and Groundwater Hydrology
5) Publication of Results: papers and presentations at national and regional meetings on Science Education

Year 2

1) Studies and Evaluations: comparative studies between the text-based product and the first graphical prototype at all four sites, with comparative evaluations of all four sites
2) Workshops: follow up workshops with participants, and an end-of-year presentation and workshop hosted at NDSU for the benefit of teachers in the Upper Midwest region
3) GUI Design and Development: implementation of text-based versions of modules completed in the prior year
4) Module Design and Development: implementation of Bulk Earth and Potential Field modules
5) Publication of Results: papers and presentations at national and regional meetings on Science Education
6) Dissemination: begin search for a national publisher

Year 3

1) Studies and Evaluations: continuing evaluation of classroom experience with new modules, and GUI interface studies.

2) Workshops: continued solicitation of feedback from collaborators
3) GUI Design and Development: a finalized version ready for publication
4) Module Design and Development: implementation of Structural Geology and Paleomagnetism modules
5) Publication of Results: papers and presentations at national and regional meetings on Science Education
6) Dissemination: national publication of the Geology Explorer materials; initiate search for a publisher for an edited collection of articles on the development of Virtual Worlds for education and the Geology Explorer experience.

7. Related Work

Far and away the most common approach to implementing synthetic multi-user environments is the text-based MUD: the multi-user, text-based, networked computing environments that are mostly for "gaming." MUDs, or Multi-User Dungeons, are an outgrowth of computer chatlines and bulletin boards plus the popularity of adventure role-playing as exemplified by Dungeons and Dragons. They are environments which one can log into from a terminal connected to the Internet, and then interact in text with objects, places, and other players within a gamelike setting (Carlstrom 1992).

In a recent search of the World Wide Web it was clear that MOOs for different ability levels are becoming a reality. Amy Bruckman, a doctoral student at the Massachusetts Institute of Technology has built a programming language to make it simpler for children to construct objects and participate in MOOs (Bruckman, 1993). She has combined construction and community in the hope of creating a constructionist learning culture in her MOOse-Crossing MOO.

MOOs have shown their importance in elementary schools. Two in particular, MariMuse, and MicroMUSE have been geared so that elementary school students can participate full-time. One notable success has been on underachieving students who had left school. These students reportedly became involved, started to form friendships, and began to take a greater interest in school (Poirer 1995).

Mineral Venture by Eighteen Software is a recently developed software environment that simulates business-oriented mineral exploration from a technical and economic perspective. This is not a multi-user spatially oriented exploration system, but rather a simulation intended to pose planning and resource management problems that geologists routinely face. PetroQuest (www.geology.utoronto.ca/~bures/PetroQuest.html) is a similar internet-based petroleum exploration simulation developed at the University of Toronto. It combines an economic simulation with a geologic mapping exercise.

SELL is a multi-playered, networked game that teaches basic marketing and micro-economic concepts. Players are immersed in a simulated environment where they are expected to save a failing retail outlet. The tools of the retail trade, (hiring, advertising, ordering, pricing), are made available, and the underlying simulation is crafted to respond to game play in plausible ways (Slator and Chaput, 1996; Hooker and Slator, 1996).

Programming Land MOO (Hill and Slator, 1997), at Valley City State University which is being developed as an adjunct to programming classes. The MOO contains material that parallels an introduction to programming in C++. The course is modeled as a Virtual Lecture built using the active museum metaphor.

A number of virtual laboratories and interactive exercises have been implemented as software or as web experiences. These laboratories might show the student pictures of petrographic thin sections (http://geologyindy.byu.edu/Petroglyph/Petrohome.htm), or ask them to make calculations in an interactive environment. Many of these "virtual laboratories" are an important type of electronic replica of a conventional laboratory experience.

Thermobarometry, by Geoff T. Nichols, calculates pressures and temperatures for garnet - cordierite - spinel - sillimanite/kyanite - quartz anhydrous or hydrous pelitic assemblages. It produces pressure vs. temperature graphs of the calculated isopleths (http://www.es.mq.edu.au/geology/geoff/geotherm/html/). The MELTS Supplemental Calculator by Mark Ghiorso at http://gneiss.geology.washington.edu/~ghiorso/MeltsCALC/ allows users to compute online the thermodynamic properties and/or component transformations of mineral solid solutions. A Java version of MELTS is available at http://melts.geology.washington.edu/. Activity Diagram Tutorial, by T. H. Brown, takes the user through the construction of an activity--activity diagram in the system gibbsite, kaolinite, K-mica, potassium feldspar, and quartz. During the tutorial, the student is asked to complete a calculation and input the answer. Answers must be within a certain range of the correct value for the student to be allowed to continue with the tutorial (http:// www.science.ubc.ca /~geol323/acttutor/).

We, however, propose a new direction in virtual environments: an interactive, multi-user, role-playing experience that facilitates a student's "Journey to the Center of the Earth."

8. Experience and Capability of PI’s

The NDSU World Wide Web Instructional Committee (WWWIC; McClean et al. 1999; Slator et al. 1999a, 1999b) is currently engaged in several virtual/visual development projects: three are NSF-supported, the Geology Explorer (Saini-Eidukat et al. 1998, 1999; Slator et al., 1998; Slator et al. 1999c; Schwert et al. 1999), the Virtual Cell (McClean, 1998; White et al. 1999a, 1999b), the Visual Computer Program (Juell 1999), and the ProgrammingLand MOO (Hill and Slator, 1998; Slator and Hill 1999). Shared goals include the mission to teach Science structure and process: the Scientific Method, scientific problem solving, deduction, hypothesis formation and testing, and experimental design. The individual goals are to teach the content of individual scientific disciplines: Geoscience, Cell Biology, Computer Science in the "active learning" paradigm (Reid 1994).

The Geology Explorer group (Slator, Schwert, and Saini-Eidukat), has been working together on the design and implementation of virtual environments for education since the Fall of 1996, immediately after Slator arrived on the NDSU campus. The group's efforts, and the demonstrations of progress in the development of the Planet Oit simulation, has had several beneficial effects. In no small measure, it was the success of this group that inspired similar virtual education projects on campus, including the Virtual Cell, the Visual Computer Program, the ProgrammingLand MOO as well as others.

There are a total of 48 individuals involved in WWWIC projects at the present time: 8 faculty (2 Computer Science, 2 Geoscience, and one each from Botany/Biology, Plant Science, Business, and Sociology/Anthropology); 22 Master Degree students (21 Computer Science, 1 Sociology/Anthropology, 5 as paid employees and the rest working on their MS projects); 3 Ph.D. students in Computer Science (1 as paid employee, 1 on an EPSCoR FLARE grant); 12 undergraduates (8 Computer Science, 4 in other majors, 4 as paid employee, 1 on an EPSCoR Science Bound grant, and the rest doing Independent Study projects); and 2 graphic artists, both former students, working as part-time employees.

Brian M. Slator trained with Dr. Yorick Wilks in the field of Artificial Intelligence and Natural Language Understanding, where he specialized in lexical knowledge representation and semantic parsing. He has published several articles in this area, as well as co-authoring the definitive book on the subject, Electric Words, published by MIT Press. He later worked for Dr. Roger Schank at the Institute for the Learning Sciences at Northwestern University where he developed innovative hypermedia systems for education, including the first published accounts of a working ASK-system (Slator and Riesbeck, 1992), and the Organizational Change Advisor (Bareiss and Slator, 1991), which pioneered the job-aid style of what are now called performance support systems. In addition to his MIT Press book, Slator has published in IEEE Computer and the Communications of the ACM (twice). His primary research interest is educational media, and particularly the idea of immersive, role-based environments, which is now the central theme of the WWWIC group.

Donald P. Schwert has taught geology for 21 years, specializing in surficial geology (physical geology, geomorphology, and glacial geology) and leading a diversity of field courses. His physical geology course has a semester enrollment exceeding 400 students. Concerned about administrative policies, common at many colleges and universities, of "Pile them deep, teach them cheap," in introductory-level courses, Schwert has working on new ways to transform his own large-section classes into better learning environments.

Bernhardt Saini-Eidukat has used computer modeling for teaching geological concepts in his geology courses in the past (spreadsheets, standalone programs) but has worked to make this type of interactivity available over the internet. An example of a web-based exercise to model flood frequencies in rivers was described in Saini-Eidukat (1998).WEB-PHREEQ is a web-based front-end to the UNIX chemical model PHREEQC (Saini-Eidukat and Yahin, 1999).

9. Evaluation Plan and Assessment Research

Dr. Richard Beckwith, Intel Corporation, will design and supervise the evaluation and assessment studies. Dr. Beckwith is a Cognitive Psychologist with many years of experience in this field. In this project his role will be to organize our efforts in collecting and analyzing data collected from students and teachers on using the Geology Explorer and incorporating it into their curriculum.

In active learning environments assessment of student learning is most usefully understood in terms of student problem-solving performance. We approach assessment in two ways: objectives and outcomes, and subjective evaluation. It is our intention to demonstrate the validity of our pedagogical approach using both forms of assessment and thereafter rely strictly on objectives and outcomes for student assessment. Briefly, the assessment goal is to determine the benefit to students derived from their "learn by doing" experience on Planet Oit. The assessment strategy rejects the notion of standardized multiple choice tests as an adequate instrument in this pedagogical context. While there are, indeed, facts and concepts acquired in the course of exploration, which are neatly packageable and testable with objective instruments, the effect on student learning in that arena will not be significant, nor would we expect it to be.

Therefore, the assessment protocol designed for the Geology Explorer is a subjective one that seeks to measure how student thinking has improved. During Fall 1998, the entire Physical Geology class (approximately 400 students) were given the opportunity to participate in an experiment to evaluate the effectiveness of Planet Oit on conceptual learning. All students were asked to answer open-ended scenario-based questions before and after the experiment (Fig. 1). These scenario questions were word problems that presented the student with a situation that a field geologist might be confronted with. Students responded to the question with a narrative answer, which was evaluated according to an established protocol.

Students were divided into three experimental groups: two groups were matched to ensure equal distributions of technological ability and were asked to experience Planet Oit or an alternate internet-based activity equal in estimated time-on-task; the third group did no additional activity. Then, after the players had experienced an extended exploration of Planet Oit (or alternative exercise), they were given a similar post-test survey with different but analogous problem solving scenarios, and asked again to record their questions and impressions. These documents were then compared with the pre-test versions for evidence of improved performance. If players exhibited a better understanding of the problem solving scenarios, this creates the clear implication that they have learned from the experience.

Analysis of the data indicates that students that participated in the Planet Oit experience performed significantly better on scenario questions compared to those that participated in the alternative exercise or those who did no additional activity. Based on the results of ongoing statistical analysis of the experimental data and on results from cooperators at Minot State University and Discovery Junior High School, we will refine the assessment protocol for future iterations of the exercise.

a. Objectives and Outcomes:

When learners join the synthetic environment they are assigned goals, selected by content matter experts to be appropriate to the learner's experience. Goals are assigned point values, and learners accumulate objectively measured scores as they achieve their goals. The goals are taken from a principled set, where easier goals are followed by more advanced ones.

Similarly, certain goals in a set are required while others are optional. In this way, designers can insure that highly important concepts are thoroughly covered while allowing the maximum flexibility to the learner. Subject matter experts identify teaching objectives in more-or-less traditional ways, while learner outcomes are assessed in terms of the performance of specific and authentic tasks. This is the particular strength of learn-by-doing immersive environments, that a learner's success in achieving their goals provides an automatic assessment of their progress.

> Lately you and your best friend have been experimenting with “new age” forms of relaxation and health improvement. One day your friend tells you that there is going to be a Crystal Power Retreat at a nearby national park and you can’t resist.
>
> It's a beautiful summer night, and you spread out your sleeping bag after a fun day of looking at exhibits and demonstrations. Your souvenir of the day is a beautiful quartz crystal you purchased from a vendor. You are tired from the days activities, but are unable to sleep as something hard is digging into your back.
>
> You grope around and dislodge a hard, clear, thumbnail-sized crystal.
>
> Your friend says, "Cool! I'll give you five bucks for that."
>
> What do you do?
>
> List the things you would consider in your decision.
>
> List the questions you would ask yourself, and reasons behind those questions.

Figure 1: A sample scenario

b. Subjective Assessment Protocol

One proven method of subjective learner assessment is pre- and post-test interviews. In Bell, Bareiss, and Beckwith (1994) an innovative approach is employed. A pre-test interview is conducted in which the interviewer recounted a problem-solving scenario to the individual subjects. These narratives take the form of stories about facing problems in the domain of interest. The subjects were then encouraged to pose possible solutions and were allowed to ask any questions that came to mind. The interviewer was armed with a small set of additional facts, with which to answer questions, and made note of whatever issues the subject attended to in the course of the interview. Subsequent protocol analysis showed this method was effective at uncovering the variables deemed important to the subject in terms of solving the problem.

Subjects were then exposed to the particular teaching or training system being tested. Afterwards, subjects were engaged in a similar post-test interview session, and advances in student learning was recorded and evaluated in terms of students recall of important problem solving variables.

This method of learner assessment was shown to be effective, and is particularly attractive in requiring generative behavior from learners. Unlike objective tests that present alternative answers for learners to choose from, this method was able to gauge recall rather than recognition.

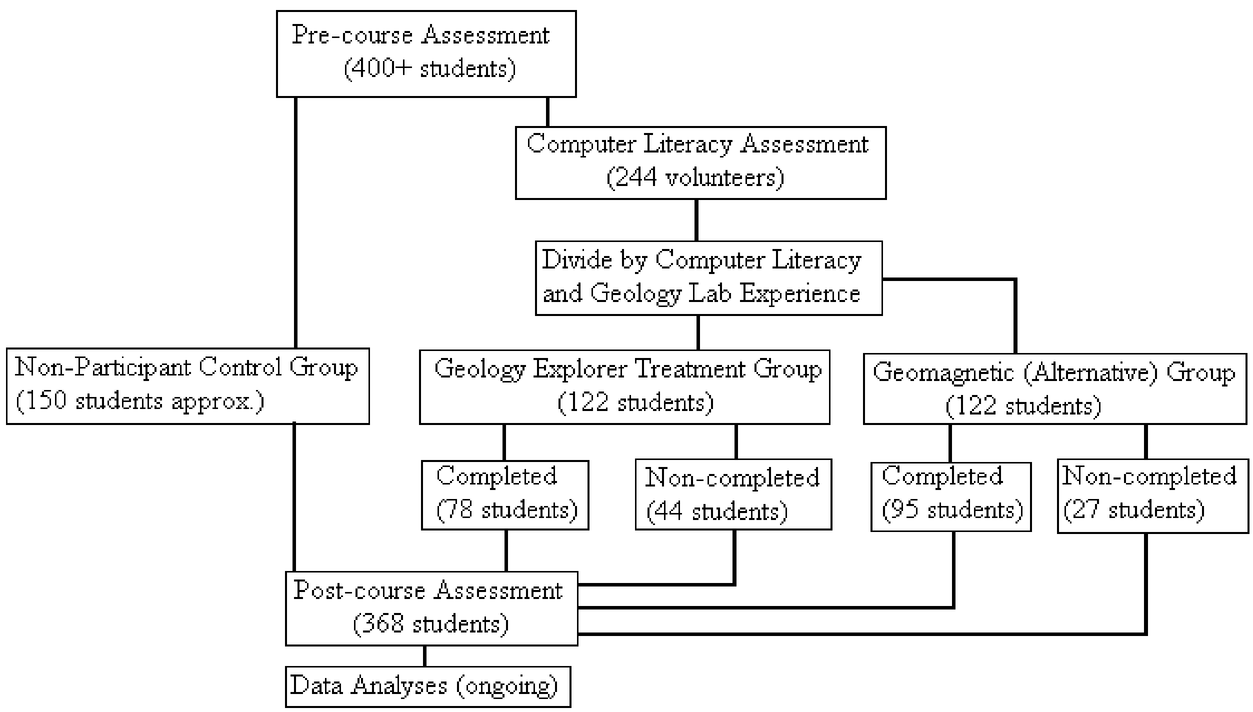

Figure 2: Assessment Protocol

c. Method

1. On the first day of the Fall, 1998, semester, all students (>400) enrolled in NDSU's Physical Geology (Geo120) completed a "pre-course" assessment scenario (Fig. 1).

2. At mid-semester, all students enrolled in Physical Geology were invited to participate in an evaluation of "web-based geologic software" in exchange for 25 extra credit points. Of the approximately 400 students, 244 volunteered. This cadre of volunteers was then divided into two evaluation groups, split equally relative to computer awareness, gender (evaluated by survey), geologic laboratory experience, and total number.

2.1 One evaluation group was assigned to the Geology Explorer, where they were required to complete 500 points worth of goals. Each student was given a two page description of the task and a list of URLs providing background information, a graphical map of the planet, and an online user card. Of the 122 students assigned to the Geology Explorer exercise, 78 completed the requirements of the project (Fig. 2).

2.2 The second evaluation group was assigned to complete a geomagnetic/map analysis project of similar rigor to that of the Geology Explorer. This group was required to obtain basic map and elevation data and then interact with those data through the National Geophysical Data Center web site. Each student was given a two page description of the task and a list of URLs providing supporting information resources. Of the 122 students assigned to the geomagnetic exercise, 95 completed the requirements of the project (Fig. 2).

3. On the last day of the semester, all 368 students still enrolled in Physical Geology completed an assessment scenario similar to that given on the first day (#1, above) (Fig. 1). Thus, students who participated in the Geology Explorer exercise could be assessed for learning performance versus two control groups: 1) those who participated in the web-based geologic software exercise of similar rigor and 2) those who did not participate in any additional exercise at all.

In addition to this formatted assessment, every student involved in the Geology Explorer exercise was automatically tracked through the program's software relative to such factors as:

* time on task
* completion of assigned (100 point) goals
* completion of unassigned (25 point) goals

* experiments (field tests) conducted

* movements through the virtual environment

* requests to the online help system and visits from tutoring agents

Our preliminary analysis of these data (currently unpublished) show a statistically significant increase in performance on geological problem solving tasks, proving that this system is an effective educational product.

	Number of Students	**Pre Experiment Mean Score**	**Post Experiment Mean Score**
Control Group	161	9.3	25.6
Alternate Group	93	8.5	24.4
Planet Oit Group	76	6.8	35.9

Note: mean scores are the average score of each group, with scoring on a scale from 0 to 80

Scores were evaluated using a General Linear Models test (GLM).

The GLM was used to test two statistical hypotheses:

H(0): all three means are statistically equal

H(1): at least one of the means is statistically unequal to the others

	Pre-Experiment Data	**Post Experiment Data**
F-value	.094	6.32
Alpha Level	39.3%	0.2%
H(0)	True	False

Specific results from the GLM test show that the pre-experimental scores were statistically equal for all three groups. F-value was .094, resulting in an alpha level of 39.3%. Thus, H(0) can not be refuted. The means of each pre-experimental group are statistically equal.

Specific results from the GLM test show that the post-experimental scores were not statistically equal for all groups. F-value was 6.32, resulting in an alpha level of 0.2%. Thus, H(0) can be refuted, and H(1) is assumed true. Results of a Duncan test showed the Planet Oit group was classified as significantly different from the other two groups, with the nature of the significance being a higher average score for the Planet Oit group.

Thus, students in the Planet Oit experimental group performed significantly better than students in the Alternate or Control groups**.**

10. The Future of Planet Oit: Dissemination of Results

The proposed project completes development of the Geology Explorer to such a point where it should be commercially attractive, with future product development to be self-sustaining through royalty income. Our plans include increasing visibility and marketability of the product as well as interfacing with business partners to launch the Geology Explorer as educational software appealing to large audiences of students. To enhance dissemination and commercialization, we are:

1) Providing free demonstration software: To increase both interest and potential market for the graphical-based Geology Explorer, the already-completed, text-based first version of the software is now being offered to the public at no charge. Users, including teachers and students of large-enrollment classes, are invited to obtain logins and play the text-based version. By providing this early version of the software for free and encouraging teachers to incorporate it into their earth science/geology curricula, we hope to spark market demand for the graphical version, as soon as it is launched.
2) Developing a business plan: An NSF-ND-EPSCoR Phase 0 TRIC (Technology Research into Commercialization) grant for $3,500 was awarded for this aspect of the project in May, 1999. This funding is being used to examine the commercial potential of the Geology Explorer as an educational software. Specifically, the grant is allowing us analyze the existing large assessment data collection and answer questions that will help lead to a commercial prototype. Demonstrating the pedagogical value of the game will provide us a stronger position when approaching a potential educational software business partner. We are seeking a partner to join in an application for a Small Business Innovation Research (SBIR) grant, with the plan being to submit a Phase I SBIR proposal under "Topic 25. Education and Human Resources."
3) Partnering with publishing companies: As one option in this dissemination component, we are exploring the prospect that the interface to the Geology Explorer software will be packaged as a

CD bundled with earth science and physical geology texts. A student thus buys unlimited access to the server-side software by purchasing the CD. The main software remains on the server host, where it can be constantly serviced and upgraded. By partnering with a large publishing company, we gain access to a national market and to the company's editorial and graphics staff. Royalties from these sales are to be returned to product development via contractual arrangements with such a company arranged through the NDSU Research Foundation.

11. Equipment Justification

The equipment request for this project is $13,000 over the course of three years, of which NDSU is providing a 50% match of $6,500. In year one, two PC workstations are requested for student software and content development. In year two, one laptop PC is requested in order to present results at national meetings; this laptop will also be a recruiting tool in our dissemination plans, as we give demonstrations to our contributors and potential collaborators. In year three, one server PC is requested (outfitted with extra memory, extra disk space, and better-than-average network cards), in order to insure the best possible performance when our simulation begins to see national-level distribution.