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Virtual environments for education

Brian M. Slator[a], Paul Juell[a], Phillip E. McClean[b], Bernhardt Saini-Eidukat[c], Donald P. Schwert[c], Alan R. White[d], Curt Hill[e]

[a]*Departments of Computer Science,* [b]*Plant Science,* [c]*Geosciences,* [d]*Botany/Biology, North Dakota State University, Fargo, ND 58105, USA,* [e]*Mathematics and Computer Science, Valley City State University, Valley City, ND 58072, USA*

WWWIC, the NDSU World Wide Web Instructional Committee, is engaged in developing a range of virtual environments for education. These projects span a range of disciplines, from earth science to anthropology, and from business to biology. However, all of these projects share a strategy, a set of assumptions, an approach to assessment, and an emerging tool set, which allows each to leverage from the insights and advances of the others.

1. Introduction

The NDSU World Wide Web Instructional Committee (WWWIC [13, 21, 22, 29]) is engaged in several virtual/visual research and development projects: three are NSF-supported, the Geology Explorer [17, 18, 20, 27, 28] the Virtual Cell [12, 31–33] the Visual Computer Program [10] and the ProgrammingLand MOOseum of Computer Science [7, 24]. These have shared and individual goals. 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 and computer science.

In addition, WWWIC is applying what has been learned in science education to new domains: history, microeconomics, and anthropology. Further, WWWIC has active research projects in three highly related areas: (1) qualitative assessment of student learning, (2) tools for building virtual educational environments [9, 30], and (3) intelligent software tutoring agents [23, 25].

The WWWIC programme for designing and developing educational media implements a coherent strategy for all its efforts. This strategy is to deploy teaching systems that share critical assumptions and technologies in order to leverage from each other's efforts. In particular, systems are designed to employ

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consistent elements across disciplines and, as a consequence, foster the potential for intersecting development plans and common tools for that development.

2. Geology Explorer

Geology Explorer is a virtual world where learners assume the role of a geologist on an expedition to explore the geology of a mythical planet. Learners participate in field-oriented expedition planning, sample collection, and ‘hands on’ scientific problem solving. The Geology Explorer world is simulated on an Object Oriented Multiuser Domain, the Xerox PARC LambdaMOO [2, 3]. A text-based version of Geology Explorer was tested in an introductory geology class during the summer of 1998. Results of that test were used to prepare for a larger test in the same geology class during autumm 1998. A graphical user interface to the Geology Explorer is in the process of design.

To play the game, 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 a sequence of exploratory goals. 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 the role-based elements of the game. 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.

The Geology Explorer prototype can be visited at URL: *http://www.cs.ndsu.nodak.edu/∼slator/html/PLANET/*.

3. Virtual Cell

The Virtual Cell (VCell) is an interactive, three-dimensional visualization of a bio-environment. VCell has been prototyped using the Virtual Reality Modeling Language (VRML), and is to be available via the Internet. To the student, the Virtual Cell looks like an enormous navigable space populated with 3D organelles. In this environment, experimental goals in the form of question-based assignments promote deductive reasoning and problem-solving in an authentic visualized context.

The initial point of entry for the Virtual Cell is a VRML-based laboratory. Here the learner encounters a scientific mentor and receives a specific assignment. In this laboratory, the student performs simple experiments and learns the basic physical and chemical features of the cell and its components. More notably, our laboratory procedures are crafted such that they necessitate a voyage into the Virtual Cell where experimental Science meets virtual reality. As the project progresses, students will revisit the laboratory to receive more assignments.

Periodically, the student will bring cellular samples back to the virtual lab for experimentation.

The implementation of the Virtual Cell depends on coordinating three technologies: (1) VRML visualization, (2) Java client and simulation software, and (3) a text-based MOO server. Students use a standard WWW browser to launch a Java applet. The applet provides a connection to an object-oriented, multi-user domain where cellular processes are simulated and multi-user viewpoints are synchronized. The Java applet also controls the agent-based implementation of organic constituents, and launches an interface to the VRML representation of the Virtual Cell, allowing the student to explore and experiment within the 3D representation.

The Virtual Cell prototype can be visited at URL: *http://www.ndsu.nodak.edu/instruct/mcclean/vc/*.

4. Visual Computer Program and Programming Land Museum

The goal of the Visual Program project is to provide an environment in which students can study and learn programming techniques. We provide tools to support active learning using visualizations of AI programs. These visualizations include animation, fly-through models and more interactive information models. The ProgrammingLand Museum implements an Exploratorium-style museum metaphor to create a hyper-course in computer programming principles aimed at structuring the curriculum as a tour through a virtual museum. Student visitors are invited to participate in a self-paced exploration of the exhibit space where they are introduced to the concepts of computer programming, are given demonstrations of these concepts in action, and are encouraged to manipulate the interactive exhibits as a way of experiencing the principles being taught.

ProgrammingLand is being developed on the Valley City State University (VCSU) campus as a Virtual Lecture adjunct to introductory programming language classes. Students peruse the exhibits of the museum, reading explanatory text that is displayed when they enter a room. A topic may be covered in one or more connected rooms. In addition to the displayed text there are a number of interactive demonstration objects in the museum that clarify or demonstrate the concepts. One such object is a code machine. It contains a short portion of programming language code and can perform any of the following functions: display the code; display the code with a line by line explanation of the purpose or syntax of each line; or display an execution of the code on a line by line basis. The goal of ProgrammingLand is to facilitate programming language courses, either locally or at a distance. At the beginning of this course the MOO had four wings, each incomplete. One of these was an introduction to using a MOO, each of the other three dealt with the one of the following programming languages: C++, Java and BASIC.

The ProgrammingLand Prototype can be visited at URL: *http://www.cs.ndsu.nodak.edu/~slator/html/PLANET/wwwic-pland.html.*

5. Blackwood

Blackwood is a virtual environment that simulates a 19th Century Western American town, circa 1880. The town is populated with a variety of intelligent software agents to simulate an economic environment [8, 34], representative of the times. The spatially oriented virtual environment borrows freely from historical records and digital images available on the Internet, with assistance from archives at the NDSU Institute for Regional Studies.

The educational 'game' is one where players join the simulation and accept a retailer's role in the virtual environment. Rather than everyone vying for a portion of the same economic market, roles are variable and specific. For example, in this simulation players are assigned one of eight roles: blacksmith, wheelwright, dry goods merchant, tailor, cartwright, woodlot operator, leather maker or stable operator. Future plans include extending these roles to things like mortuary services, barber shops, apothocaries, gunsmiths and so forth. Therefore, players will only directly compete against other players with similar roles, or with software agents in the same profession, but not be in instant competition with every other player [26].

Meanwhile, the economic and cultural life of the simulation is sustained by an array of software agents for saloons and gambling establishments, banks and bankers, messenger services and teamsters, newspaper publishers, and others. In the future, the environment will support period-authentic atmosphere in the form of entertainments. For example, the circus might come to town, the weekly train will arrive from the east, a cattle drive will appear on the scene, preachers and circuit judges and medicine shows will pass through, and the occasional crime will be reported.

The Blackwood Prototype can be visited at URL: *http://www.cs.ndsu.nodak.edu/~slator/html/blackwood/.*

6. Virtual Polynesia

WWWIC is in the process of designing an immersive, synthetic environment where students, in the role of anthropologist or trader, step ashore on an island in western Polynesia, in the south Pacific, near the turn of the 19th century. That island, and the culture encountered, is modelled after the Samoan islands at a time a time when Samoan culture was still unaltered by Western goods and ideas. The environment will focus on a small valley and surrounding territory which represent a microcosm of Samoan society. The anthropologist is able to observe and explore the traditional society as it had developed to that time. He/she is also able to witness the contact of cultures as the trader enters the picture. While the environment will be fictitious, it will be based on careful attention to actual Samoan materials and cultural traditions.

Virtual Polynesia is another experiment in creating virtual worlds where more than one role is available to students. In this scenario, the most obvious roles are trader and anthropologist. The trader will visit the culture looking to exchange Western goods for items in Samoan culture that would have value in the West. The anthropologist will look to the discovery of cultural artifacts that in some way illuminate our understanding of Samoan society.

7. The WWWIC Research Strategy

The WWWIC projects are designed to capitalize on the affordances provided by virtual environments. For example, to

- control virtual time and collapse virtual distance,
- create shared spaces that are physical or practical impossibilities,
- support shared experiences for participants in different physical locations,
- implement shared agents and artifacts according to specific pedagogical goals,
- support multi-user collaborations and competitive play.

Specifically, the WWWIC projects each design with the following over-arching principles.

7.1 *Role-based*

Simulated environments enable learners to assume roles in particular contexts and have meaningful, authentic experiences. In the popular culture, this approach is captured in the John Houseman adage, ‘learning not the law, but learning to think like a lawyer’. More formally, WWWIC promotes a learning strategy based on the ancient idea of apprenticeship where, in modern terms, the student progresses by ‘modelling the expertise’ of the master. These environments allow the students access to the tools of the scientist and these tools, as noted by Lave and Wegner [11] embody the practices of science. Role-based learning is learning-by-doing, but not the mere goal oriented ‘doing’ of a task. Rather, it is learning-by-doing within the structure of playing a role in context. Instead of simply teaching goal-based behavior and tactical task-oriented skills and methods, the role-based approach communicates a general, strategic, manner of practice [14]. Authentic instruction [1] allows the student to participate in the practices of the working scientist.

7.2 *Goal-oriented*

Goals are important, but within the context of roles. It is through goals that obstacles leading to problem solving are encountered. It is within the local goal framework that techniques and methods are learned and rehearsed. Practice and repetition in problem-solving is how apprentices learn the master’s craft. Goals provide problems to solve.

7.3 *Learn by doing*

When experiences are structured and arranged such that playing a role in the environment illustrates the important concepts and procedures of the simulated domain, students are able to ‘learn by doing’ [4]. Experiences are the best teachers.

7.4 *Immersive*

The combination of role-based scenarios and spatially oriented simulations is conducive to an immersive atmosphere. The concept of immersion has long been shown valuable in foreign language learning (where, it is anecdotally understood, the key moment arrives when the learner succeeds in reaching the point where they are ‘thinking in X’, where X is French, German, Farsi, or whatever). Immersion, then, is elemental to the concept of role-based learning where it is the strategic thinking of the master within an authentic contenxt the apprentice eventually learns to model.

7.5 *Spatially oriented*

WWWIC simulations are spatially-oriented to leverage off the natural human propensity to towards physically plausible context. In this way, simulations promote the ‘willing suspension of disbelief’ which in turn reinforces the role-based elements of the environments.

7.6 *Exploratory*

Exploratory simulation means enabling students to control their experience and pursue their own interests. This approach, usually referred to as user-centred design, promotes a pedagogical environment where learners are self-directed and given the freedom to structure, construct, and internalize their own experience [5, 6].

7.7 *Game-like*

The value of play in learning can hardly be over-stressed. Students quickly tire of rigid tutorial systems designed to teach at any cost and at some predetermined pace [19]. However, since simulations can be adaptive and responsive, playing a role in a simulation can be fun. Players will throw themselves terrier-like into an environment if it feels like a game. Insofar as possible, educational software should be engaging, entertaining, attractive, interactive, and flexible: in short, game-like [26].

7.8 *Highly interactive*

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 [16].

7.9 *Multi-user/player*

One challenge is to craft role-based, goal-oriented environments that promote collaboration as well as the more easily conceived competition. The answer lies in designing systems where student/players have multiple roles to choose from, and to carefully construct the simulation so that these roles are inherently complementary. WWWIC educational systems are uniformly multi-user, and hosted on a MOO-based client-server architecture.

7.10 *Software agents*

Software agents are implemented to exhibit authentic behavior(s) of the following types:

- *atmosphere agents*: an agent that simply lends to the local colour. For example, in an urban simulation there might be a street magician, a street vendor, a beat policena, a street sweeper, and so forth; in a museum simulation there might be visitors wandering the exhibits or vendors selling popcorn; on a planet perhaps animals roaming the desert;
- *infrastructure agents*: an agent who contributes in some way to the game-play: in an urban simulation perhaps a banker, an employee, an advertising consultant, and so forth; in a museum, one might expect a guide; on a planet, another kind of guide or a laboratory assistant;
- *tutoring agents*: an agent that monitors player moves, and visits players to give them advice in the form of expert stories and cases, or in some other way assists players in learning to play. These will represent expertise or past experiences of other players.

7.11 *Unintrusive tutoring*

A key feature of educational media is the ability to tutor students. In WWWIC environments, 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.

7.12 *Intelligent software tutoring agents*

We implement three different approaches to intelligent tutoring [23, 25], based on the knowledge available to the tutoring agent.

(1) *Deductive tutors* provide assistance to players in the course of their deductive reasoning within the scientific problem solving required for the accomplishment of their goals.
Example: intelligent tutoring agents in the NDSU Geology Explorer [17, 18, 20, 27, 28], which work from knowledge of the rocks and minerals, and knowledge of the 'experiments' needed to confirm or deny the identity of a rock or mineral. Three opportunities for deductive tutoring present themselves:

- an *equipment tutor* detects when a student has failed to acquire equipment or instruments necessary to achieving their goals;
- an *exploration tutor* detects when a student has overlooked a goal in their travels;
- a *science tutor* detects when a student makes a wrong identification and why (i.e. what evidence they are lacking); or when a student makes a correct identification, but with insufficient evidence (i.e. a lucky guess).

(2) *Case-based tutors* provide assistance to players by presenting them with examples of relevant experience. This is accomplished by:

- creating a library of prototypical cases of success and failure;
- treating the student's experience as though it were a case;
- matching the student's case with the library and retrieving the most similar, relevant case for remediation.

(3) *Rule Based tutors* provide assistance by:

- encoding a set of rules about the domain
- monitoring student action looking for one of these rules to be 'broken'
- 'visiting' the student to present an expert dialog, or a tutorial.

7.13 *Shared courseware tools*

Creating virtual/visual worlds is an intensive process in terms of pedagogical design, knowledge engineering, and software development. Having gained experience in the hand-crafting of these systems, WWWIC is now in the process of designing and developing an integrated library of software tools to substantially streamline the development of future worlds [30]. These tools primarily support simulation and agent building, and are of the following types:

- *Virtual Abstraction Tool*: Jia [9] implements a first version of a graphical tool for building abstraction hierarchies in LambdaMOO. This tool enables the creation, deletion, renaming, and recategorizing of objects. Tools of this sort enable content experts to visualize the structure of the knowledgebase and assist with creating the taxonomic structures for representing conceptual knowledge.

- *Virtual Entity Tool*: we are implementing a tool to employ an entity template system with a form-filling interface to enable creation of multiple instances of a category. For example, we will define a template for minerals that specifies the properties indigenous to minerals, and ranges of values associated with each property. Then, a content specialist will create new minerals, quartz, tourmaline, talc, etc., with a graphical form-filling interface where values such as colour, texture, and hardness can be quickly and easily selected from menus. This tool is general in that any category of entity (animal, mineral, or vegetable) can be constructed with it.
- *Spatial Environment Tool*: we are implementing a spatial environment tool (i.e. a virtual map building tool) to allow environment designers to graphically create and manipulate spaces in a virtual world. By using a map-like interface, content specialists will decide on the specification of locations, such as geological formations and placement of these in relation to each other.
- *Integrated Virtual World Building Tool*: we are implementing a master tool that coordinates and manages the process of building virtual worlds. This tool supports the implementation of virtual worlds from the ground up, by giving access to the construction tools, and a 'surface' view of the world as it develops. For example, content specialists building, say, virtual space for paleontology, will use the *Virtual Abstraction Tool* to create the hierarchy of concepts related to fossils. Then the *Virtual Entity Tool* will be used to create an inventory of fossils in different categories. Meanwhile, the *Spatial Environment Tool* will be used to create canyons and mountains where the fossils will reside. The integrated tools set, which we are calling GUMI Suite (Graphical User-friendly MOO Interface) will support the developer's exploration of the virtual world as they develop it. At the same time, the integrated tool will support the *Deductive Tutoring Agent Tool* (described next), since they operate on the same objects.
- *Deductive Tutoring Agent Tool*: we are implementing a tool to

  (1) provide a menu of virtual testing equipment and the range of values each produces—from this a subject matter expert can choose the appropriate instrument-value pairs;
  (2) provide a menu of substances in the same category, to serve as a template; and
  (3) check other substances to insure a unique set of plausibly sufficient criteria for each.

These three functions will insure that tutoring is supported on all identification tasks and will have the further benefit of checking for consistency of artifacts in the synthetic world. This tool will be integrated into GUMI-Suite, described above.

The ultimate aim in developing software tools is to support the construction of synthetic environments and move development into the hands of content specialists, teachers, and curriculum developers, rather than computer programmers.

7.14 *Qualitative assessment*

Developing methods for the assessment of student learning are a central element of this research. Briefly, the assessment goal is to determine the benefit to students derived from their 'learn by doing' experiences.

Our 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, our assessment protocol is a qualitative one that seeks to measure how student thinking has improved. To do this, players are given a pre-game narrative-based survey where they are told short problem solving stories and asked to record their impressions and any questions that occur to them. These surveys are analysed for the presence of what could be considered 'important' domain or problem-solving concepts or procedures.

8. Conclusion

The main goals of science education is to teach students a framework of basic principles and approaches that can later be used to solve science-based problems. In addition, specific scientific fields are content based. For students to have a successful appreciation of science, they must master the content of a discipline. Scientists can be seen as a community or culture whose members share a set of beliefs and practices. Science, in this view, can be seen as a 'community of practice' (e.g. [15]). The challenge for science educators is to employ educational methods that deliver both the basic principles and the important content material, in the context of this community and in a meaningful way.

Choice of computer-based courseware significantly affects how and to what depth principles and content are available to the student. For example, it was not that long ago that engineering students were given the overnight assignment of measuring the load on a beam. With the advent of sophisticated CAD software, the overnight assignment can now be to design an entire room in which all of the load bearing walls meet specific code requirements. The impact of the software is two-fold. First, the principle of load is taught relative to a real-world problem context: the design of a room or even a building. Second, content is delivered at a faster rate because student learning is assisted by the use of professional tools. Over a period of time, what were once advanced topics will be taught earlier in the curriculum. This evolution will in turn lead to a more meaningful education.

Other issues are also affecting the science educators choice of pedagogical methods. The student body is more diverse than ever on any student campus. The demographics of the student body suggest the average age of the student body is older with a greater percentage of the students having to simultaneously support their education by outside employment. The students also have a different, more practical, attitude toward their education. All of these factors require the educator to search for instructional methods to augment the lecture–laboratory approach to science education.

Computer technology addresses some of these issues. For example, multimedia-based delivery of course materials offer multiple modes that reach students with different personal styles. Network-based instruction tools can relieve some of the place-bound and time-bound problems of the modern student. Finally, actively engaging students with unique visualizations and role-based simulations with dynamic interfaces has to potential to engage in ways that lecture-laboratory approaches can never hope.

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For further information on our virtual worlds software development , visit the NDSU WWWIC web site at URL: *http://www.cs.ndsu.nodak.edu/wwwic/*.

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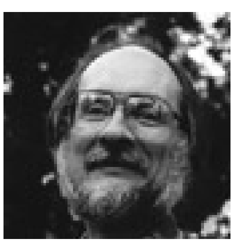
Dr Brian Slator is an Associate Professor of Computer Science at North Dakota State University. His research interests are Artificial Intelligence and Intelligent Educational Media. He is currently involved in several research projects in the area of immersive, multi-user, virtual environments. He is also involved in research for developing software tools for constructing virtual worlds, and innovative methods for assessing learning in virtual environments.



Dr Paul Juell is developing visualization tools for the AI classroom. This work is a direct outgrowth of his active research in both AI and classroom technology. His AI research is primarily aimed at developing and improving tools. His classroom technology work has included internet based distance education, changing the campus to include Web based instructional components, and video conferencing tools as part of normal classroom activities.

Dr Phillip McClean is a Professor of Plant Sciences at North Dakota State University with teaching responsibilities in genetics (http://www.ndsu.nodak.edu/instruct/mcclean/plsc431) and plant molecular genetics (http://www.ndsu.nodak.edu/instruct/mcclean/plsc731/index.htm). Dr McClean received the Excellence in Teaching–Early Career from the NDSU College of Agriculture in 1994 and the Peltier Award for Innovation in Teaching from NDSU in 1998. Dr McClean was also honoured in 1999 with an Innovative Excellence in Teaching. Learning and Technology Award at the 10th International Conference on College Teaching, Learning and Technology.

Dr Bernhardt Saini-Eidukat is a petrologist, mineralogist and economic geologist who is currently working in three research areas: (1) the tectonomagmatic evolution of the Somoncura area of northern Patagonia, Argentina, using radiogenic isotope methods; (2) inquiry into how active learning of geologic concepts can be promoted by using role-playing software; (3) the occurrence of a silver-rich massive sulphide deposit in the Lumby Lake region of Ontario. An Assistant Professor in the Department of Geosciences at North Dakota State University, he teaches a variety of courses including Physical Geology, Mineralogy, Petrology, Geochemistry, Hydrogeology, Environmental Geology, and Field Courses.

Dr Donald P. Schwert is a surficial geologist, with a research specialty in ice age environments. Being a professor in a large-section (>400 students) class of Physical Geology has interested him in the development and application of software that will help transform such a class into a better learning environment.

Dr Alan R. White is Associate Professor and Chair of the Department of Botany/Biology, North Dakota State University. His plant cell biology research interests include the structure of plant cell walls, the synthesis of cell wall polysaccharides, and the structure and functional organization of Golgi membranes in plant cells. His interests in cell biology are also channeled into the development of the Virtual Cell, a virtual environment for teaching cell biology.

Curt Hill is an Assistant Professor in the Valley City State University Mathematics Department. His main job there is to teach Computer Science classes, an occasional Algebra class, and maintain Web pages. His current research emphasis is the development of the Programming-Land MOO for on-line instruction in programming and programming languages.