Project Description

When Marshall McCluhan (1964) social thinker and media philosopher said “People want roles, not goals” he put his finger on a principle that is both ancient and prescient.

We propose a Science Learning Center for Immersive Virtual Environments in Education devoted to the study of learning in immersive virtual contexts. We call this approach "role-based" learning as it appeals to and extends the notion of experiential and exploratory construction of new knowledge through enculturative contexts and processes afforded by virtual educational environments. By establishing this Center, we create a new degree of research energy and organizational expansion required to achieve the next level of research in virtual learning environments: the study of multi-student virtual learning and cognitive outcomes.

With increased funding and formal centralization of administrative and management functions, we will produce an advanced research portfolio of scientific, scholarly, artistic, and technological contributions to the science of learning in papers and products with a potential to result in positive educational practice and policy changes. The use of virtual learning contexts is already occurring and affecting economic, technological, and social areas. We must learn more about how role-based virtual learning works, what its outcomes are, and how well it prepares future scientists, business leaders and workers, artists, and the public at large for the challenges of the future. Our vision is to continually push the boundaries of virtual learning and therefore push the boundaries of knowledge, practice, and policy.

Role-based Learning

Immersive virtual education involves role-based interaction. Roles are multiplex social statuses or identities to which are attached culturally-shared and agreed-upon sets of rights, duties, obligations, and levels of expected specialized knowledge and ability (Gluckman 1963). People live in cultural groups, and culture perpetuates itself by providing models of role behavior for society members to integrate and assimilate (Harris 1968, 1979). Enculturation is the process of cultural learning that transmits knowledge and skills from one generation to the next through observation, memorization, and performance in learning (“enculturative”) contexts (Peacock 1986, Ortner 1984, Harris 1968). Enculturation has been examined routinely in countless sociological and anthropological studies of culture change in “industrial” and “traditional” groups and societies (e.g., Rogers and Shoemaker 1971, Voget 1975, Swidler 1986, Spradley 1987, Tishman, Jay, and Perkins 1993), and, more recently, in terms of educational learning (e.g., Hagge 1995).

One illustrative example of learning and cultural perpetuation through enculturation is provided by Like-A-Fishhook Village in what is now northwestern North Dakota (Smith 1972). Like-A-Fishhook Village was an earth lodge settlement established by three sedentary tribes, who, after centuries of internecine feuding, banded together in the 1840s in the aftermath of a smallpox epidemic. The village was located on a strategically defensible bluff in the shadow of a trading post (later an army fort) as a defense against the predations of ancient enemies.

According to Smith (1972), Like-A-Fishhook Village was the last great earth-lodge village and the scene of fascinating cultural continuity and change as the three tribes learned to co-exist for mutual protection. During the time of the village, the individual tribal groups worked to preserve their own identities while both absorbing and resisting the modern influences of the white traders and conquering soldiers. There are accounts of heartbreaking struggle and uplifting accommodation, shared recollections of children crossing tribal lines for the sake of marriage and adoption, movements to preserve cultural integrity along with reluctant adaptive reliance on jobs as traders and scouts for the white government, and a remarkable account of early adoption of a certain specific new rifle that was bartered and swapped from hand to hand, passing from North Dakota to New Mexico in a week’s time.

It was an era of change, marked by fluidity, absorption, adaptation, accommodation, and ultimately transition to a new synthesized culture. Throughout all this there was learning through enculturation. The children of the tribes did not, for example, attend lectures on hunting and trading. Instead, the children went out into the world and experienced hunting and trading. They watched, they asked questions, they tried it for themselves, they failed in various ways, they received additional advice, and because they had seen it done all their lives, they learned how to hunt and trade. In the process of learning, this next generation accumulated new skills and new technologies, and learned new ways of surviving in their contemporary world. Later, with varying levels of success, they passed the knowledge and practices through the same enculturation processes to their own children.

This is a story of learning through enculturation. The main features are that the learner is informed by context as well as verbal or textual content (in a manner similar to that described by Kay 1997), and the learner develops skills and conceptual understandings that come with practicing a discipline (involving both behavior and dialogue) under the watchful eye of more experienced practitioners, eventually learning concepts and techniques that
are both new and old. The learner proceeds through various spiraling and semi-reiterative phases of learning, from knowledge function (akin to those described by Rogers and Shoemaker 1971) to schema (re)construction (similar to that described by D’Andrade 1987).

For the contemporary virtual environment learner who is the focus of the proposed Center, enculturative learning occurs in role-based immersive experiences and cognitive apprenticeship. Teaching by field work in geology and anthropology, by laboratory exercise in biology and chemistry, by residency in medicine and psychology, and by cases in business and law are all examples of “role-based learning” – that liminal performance zone where concept is put into practice and learning passes from memorizing and reciting facts to experiential knowledge shared by a specific community (Turner 1977, 1987), developing what the mathematicians call “intuition”.

Working from the critical intersection of educational technology and anthropology of learning, cognition, and performance, we are breaking new ground in learning research on the impact of immersive virtual environments (IVEs) for role-based education. Our objectives are to organize and advance scientific understanding of virtual role-based learning, innovate and expand assessment methods, and disseminate these results to an international audience. We propose a Science of Learning Center that will take the core competencies of our existing and long-term multi-disciplinary research team to a new level of scientific achievement.

**Vision**

We are scientists and scholars based in several Colleges across North Dakota State University and affiliated independent research institutions. Originally structured as the World Wide Web Instructional Committee (WWWIC; Slator et al. 1999), our expanding team’s cross-disciplinary strength derives from our long-standing history of research and practice – a record of shared, long term commitment to innovative educational technologies through a science of learning in immersive virtual role-based contexts. During the past decade, we have created a dedicated organization of multidisciplinary research integrating several coordinated initiatives in the science of learning in immersive virtual role-based contexts (Slator et al. in press).

The decade-long foundation of our work and our unifying research question is, how do students learn in virtual educational worlds, and what can be done to enhance these processes of learning to higher levels of performance? These are questions involving the relationship between humans and machines, cognition and behavior, symbolic performance and enculturation, social organization and learning, play and learning, and stress and learning. The fields involved span the biophysical sciences, social sciences, the arts and humanities. Virtual learning projects are reported from such diverse areas as medical and health sciences, political science, geology, chemistry, English, archaeology, business, microbiology, psychology, and others. In K-12, virtual learning contexts are being hand-created and launched by teachers anxious to explore a learning environment already familiar to their students. In the private sector and in government, projects are reported for training, marketing, and familiarization of duties.

The future of a science of learning in immersive virtual role-based contexts requires organizing and advancing all these appropriate partnerships among academia, industry, all levels of education, and other public and private entities. The Center will organize and advance these research projects, their coordination with various partners, and the expansion of learning research assessment at a systematic and scientific level. The Center will marshal the current strengths in the subfield and usher in a new day of virtual education.

**Strategic Plan**

The strategic plan we have followed to this point has been focused on the development of IVEs and assessment of associated learning. We propose to continue an expansion of this plan as shown in the following elements.

**Development of Environments and Assessment of Learning**

The core activities of the Center will be involved with developing IVEs for education in a range of disciplines and at a variety of levels. Central to this development is research into intelligent software tutoring agents which comprise a key element of the pedagogical infrastructure. These development efforts are complemented by research into scenario-based assessment of student learning.

**Task Modeling and Data Mining**

Intelligent software tutors depend on task models to support the kinds of interactions that will lead students to their own discoveries. Equally important is to develop a theory of behaviors in IVEs. We propose data mining
techniques (feature extraction, clustering, time-sequence-aware analysis, and “interesting pattern” approaches) to process student logs to identify categories of student errors and problem-solving strategies. These analyses will provide the structure necessary for developing advanced tutoring models and tutoring strategies.

Tools and Systems

Support of the core activities is composed of developing tools to assist with the construction of role-based IVEs, implementing new systems supporting distributed server delivery, and systems for managing research studies and collecting data.

Outreach and Teacher Training

As systems are developed to a version release our strategy is to distribute to local area teachers and teaching faculty at partner institutions, and then offer courses where the systems are explained and lesson plans are developed. We pay teachers to attend these courses and provide these software prototypes in the form of a free donation. Then we track these teachers and support them as they incorporate our systems into their teaching.

Participants in these programs come from both urban and rural settings, and from both K-12 and a range of higher education institutions, including research universities, liberal arts colleges and tribal colleges in the upper midwest region.

Dissemination and Sustainability

The story of our research group and its innovations is forthcoming in our book from Teachers College Press, Electric Worlds: immersive virtual environments for education (Slator et al., in press). This establishes our national presence and the baseline philosophy and approaches of the group. In addition, dissemination of research results will be accomplished through a new e-journal we propose to launch, the E-Journal of Immersive Virtual Environments for Education (e-JIVEE). Sustainability will be achieved through a pipeline of research results to our spin-off company, WoWiWe Instruction Co. (TIN 043676233) which will develop packaging and distribution, and provide support for users of our developed systems as they are released.

Student/Faculty Exchange Programs

Collaborative agreements with new partner institutions have been developed and a student/faculty semester exchange program with the University of Texas – Pan American (a primarily Hispanic serving institution), and the University of Paraeus in Greece, offer exciting opportunities to develop new systems and approaches to the development and study of immersive virtual environments for education. The principal motivation for these collaborations is the opportunity to examine our theories of role-based learning as an enculturative process within highly varied cultural contexts.

The Making of a Center

Role-based Immersive Virtual Environments (IVEs) for education, and the assessment of role-based learning, will be the core activities of the Center. These role-based, multi-user, content-laden systems are computerized educational games of a specific and particular design that emphasize immersion, exploration, and learning-by-doing (Slator et al. 1999). Based on the core competencies already established at NDSU, the mission of the Center will be to pioneer research and methods by extending its research program in three directions: horizontally, vertically, and laterally.

Horizontal Expansion

Horizontal expansion is simply but significantly the mission to add content to existing systems. For example, the Geology Explorer (Saini-Eidukat, Schwert, Slator, 2001), has modules for mineral and rock identification, site interpretation, and geologic mapping, and the Virtual Cell (White, McClean, Slator, 1999) has modules for organelle identification, the electron transport chain, and photosynthesis. These modules represent several hours of student engagement but still only begin to provide experience with the many activities offered in the curricula. Each of the projects currently underway has a list of horizontal expansion plans (i.e. new modules) to pursue.
Vertical Expansion

The pedagogical goals of the NDSU systems have been mainly centered on undergraduate education. The NDSU approach focuses on material that is traditionally most difficult for students to grasp from typical lecture-based presentation, and favors a more organic approach. For example, the Geology Explorer begins with a freshman level activity (mineral and rock identification), and then builds on that experience by moving directly to an interpretive geologic mapping exercise (sometimes not covered until junior year in the traditional course sequence). In other words, NDSU IVE systems build from one idea to another in the natural progression illuminated by the practice of working geologists in the field.

The idea of vertical expansion is to seek opportunities to extend the content both upward toward advanced levels and, just as importantly, downward to the public schools, the technical and community college arena, and the “informal education” opportunities of museums and other public education where there can be fewer assumptions about the prior experience of the learner.

Lateral Expansion

Potentially the most important activity of the Center will be to identify the disciplines and sub-disciplines that lend themselves to role-based learning-by-doing – and those that do not. For example, we have determined that geology and biology are natural fits with IVE pedagogical strategies. Practitioners in these sciences tend to practice their science “in the field” (where that field might be a hillside or a wet lab). Archaeology, Cultural Anthropology, botany, ecology, and paleontology might seem to be obvious extensions. However, what about psychology? Or economics? Perhaps these can be visualized within the framework. But then what about more fundamental pursuits like arithmetic and reading? Or mathematics and physics? These are not so obvious. Foreign language instruction might seem natural, since the immersive approach is central to that and distance learning communities have already been created. But, language processing and understanding in computer-based systems presents its own set of highly intractable problems. These are the confounding questions embedded in lateral expansion at the edges of our research and understanding. It seems clear there are a number of “-ologies” that will lend themselves to immersive role-based systems. But which are they? This is a central, global question the Center will seek to address. To explore these is to advance the science.

Current State of Knowledge

Virtual role-based learning research during the past decade has transformed our understanding of human-machine and cognition-culture impacts on college-level learning (UKeU 2002, Slator et al 2002, 1999, Farrell 2001, Piringer 2001, Reimer and Edelson 1999, 1998, Vaupel and Sommer 1997, Collins 1998, 1997, Linn 1995). Powerful new technologies for visual worlds and multi-user interaction combined with sciences of learning and education, have resulted in a new subfield of scientific knowledge: a science of learning in immersive virtual role-based environments. Although these new multidisciplinary research teams have increased our understanding of many aspects of human and machine learning, the scattered and uncoordinated research has left us with large knowledge gaps and little public-private sector coordination to meet the social mandate of educating students for current and future challenges in science and the workforce. Especially complex but fundamental questions, such as the difference between learning in single-user worlds and multi-user worlds, the difference in visual and non-visual worlds learning, and the relationship between real-world learning simultaneously with virtual-world learning, remain largely unexplored by virtual learning scientists. Not only do we know very little about the long-term impacts of virtual learning, we know even less about how socio-cultural experience within and outside the virtual world sculpts the learning process (Rogoff 2003b).

Furthermore, a principal concern in education is student motivation. The uninspired student often creates difficulties for instructors and themselves. However, recent studies indicate that the use of technology in the classroom not only increases student motivation, but also improves achievement (Blume 2001). Yet simply incorporating technology into traditional, teacher-centered instruction alone will not accomplish either goal of motivation or achievement. Moreover, this approach to “technology in the classroom” has actually contributed to the “digital divide” between socioeconomic groups. Low income students are frequently limited in their technological savvy as they often use computers for simple rote exercises, creating road blocks in their process of “social inclusion” in a digital society (Warchauer 2003). We address this problem with a focus on immersive apprenticeship.

The tradition of immersive apprenticeship (i.e., learning in context) as a means of transmitting culturally relevant learning is both time-honored and supported by modern research, but the actual processes involved in contextual learning only came to be studied vigorously in the last 20 years (Levine 1984:84-86, D’Andrade 1995,
and real worlds. The role-based participant, the student appears in the virtual world to self and others as an individual and unique persona (an avatar in the visual virtual worlds) capable of engaging objects and others through language and virtual communicative experience and behavior the student’s understanding of the virtual reality. Because the virtual environment provides students opportunities for authentic learning (Winn 1999).

We find that the catalyst that transforms the virtual world into a cultural learning experience can be understood as enculturation effected within the virtual enculturative conditions (Brandt 2003). Enculturation classically refers to the processes by which cultural ideas and behaviors are passed from one generation to the next (Harris 1968:11, 78-79, 132, Spindler 1974, Dix 2000). Enculturation in contemporary anthropological usage refers to cultural learning in general (Ortuno 1991). Enculturation is an intrinsically social process relying on material and symbolic context and content of experience to bridge the gap between cognizance of new ideas and practice relying on those ideas (Rogers and Shoemaker 1971).

Anthropology and Contextual Learning Activities

The anthropological contribution to a science of IVE learning involves understanding how student engagement of problems in a cultural context engages the learning process and produces outcomes in individual and group knowledge. Following examples from ethnographic studies in education (Wolcott 1991, 1985), the immersive virtual role-based environments we study can be described as cognitive artifacts for education, that is, as tools for learning. Cognitive artifacts are fundamental to most of humanity’s learning processes (Biddick 1947, D’Andrade 1989; Norman 1991). As cognitive artifacts, the virtual role-based worlds for education are constructed purposefully for student immersion in scientific and humanities problems (where immersion entails plunging into a virtual world in the role of a particular persona, as distinguished from student presence in a classroom or other traditional learning environments (Slator, Clark, et al. 2002)).

Scientists and scholars working with IVEs as worlds for learning, refer to these immersive contexts for learning as “authentic” (Lave and Wenger 1991, Naidu et al. 2000). Anthropology defines these virtually authentic worlds as cultural in the sense that the world is made up by a selection of traits from a universe of possibilities (Batteau 2000). Specifically, the world is designed to offer a limited set of facts in a rich context of scientific practice (Edelson, Pea, and Gomez, 1996).

The resulting virtual world has an effect on students that can be characterized, in part, in terms of the linguistic relativity principle as developed by Sapir and Whorf (see Swoyer 2003 for an overview of the principle in its current form). Simply put, the virtual world is limited, and hence it constrains through language and symbolic communicative experience and behavior the student’s understanding of the virtual reality. Because the virtual reality is an archetype of real-world reality, the student’s understanding of the virtual problem is transferable to real-world problems, using the same class of psychological and social processes that are associated with individual learning through problem-exposure (Spindler 1955), unceremonious social coaching (D’Andrade 1981), and innovation diffusion found within a cultural system (Rogers 1962). Current study of simulation learning theory argues from anthropological participant observation of simulation studies among college students (e.g, D’Andrade 1981, 1987, Owen 2002a, 2002b), and transference of these arguments to analogous situations in the virtual world (Brandt 2003). We find that, by taking the role of scientist, scholar, or artist, the student advances in the problem scenario by learning disciplinary content and, more significantly, by learning to think in patterns appropriate to that discipline, as shown through the use of methods, tools, and analytical approaches learned in the virtual world and demonstrated in both the virtual world and real world (Clark et al. 2002, Slator and MacQuarrie 1995). This is the goal of the IVE learning environment: that what counts is not so much the work produced by the students in that environment, but the students’ enhanced ability to produce work in an appropriate way (to think “scientifically”) by way of contextual reasoning (Sidorkin 2002).

The virtual role-based worlds are specially constructed to engage the student at theory and method levels. As a role-based participant, the student appears in the virtual world to self and others as an individual and unique persona (an avatar in the visual virtual worlds) capable of engaging objects and others through language and virtual physical behavior. The role may be a scientist or businessperson or engineer, depending on the discipline involved and the goals built into the simulation. Regardless of the environment, the pattern of engagement with theory and method in the virtual world is driven by individual experiences and “other-dependent learning” in both the virtual and real worlds.
Other-dependent learning involves “conditions of informally guided discovery” (D’Andrade 1981:186). We learn best not on our own but through engagement with others. Student engagement in the world is both formal and informal, made possible through interaction with things, software agents, and other people online in the virtual world. These other people include instructors whose virtual behavior takes the form of “powerful hints and occasional correction,” so important to other-dependent learning (op cit). Similar learning theory is found among business management theoreticians, who emphasize the role of people who are “third party brokers” and “go-betweens” (Nooteboom 1999, 2000). The interaction of the instructors with the students in the virtual world is deliberately patterned and part of the selection of the traits (elements) of the world. The patterns of theory and method constructed into the virtual world are recognized at various levels of cognizance by the students as they proceed to work with the problems presented in the scenarios (seemingly similar to processes of cognizance and learning as reported by D’Andrade (1984)). A student’s recognition of all the patterns in the world is indicative of learning stages, increasing comprehension requires many rearrangements of understanding. Hence, as the student learns, so the understanding of the virtual world changes for the student. Learning is both accumulative and transformational, whether the learning environment be constructed for science (e.g., Van Haneghan et al. 1992) or the workplace (e.g., Clancey 1995).

To interact and learn in the virtual world the student must engage virtual objects, virtual avatars (software agents), and real-time personas of real people co-resident in virtual space. Formal teaching of virtual engagement learning can only reach rudimentary levels. The students are given a vocabulary and interaction etiquette guidelines. Once the student has a handle on the basic tools of engagement, the student is given goals and the reasons for being in the virtual world. The students are given simple tasks at first, while they learn to use the technology that is the mechanism of physical engagement in the virtual world. The students are encouraged to work together. But the students have no real experiential understanding of the virtual world until they are in it.

Invariably some of the students have previously experienced virtual worlds and virtual role-based interaction. These experienced students explore with confidence the world and act as informal mentoring agents to newer students. The more experienced virtual student teaches others how to get along in the virtual world, usually through various informal behaviors and discourse. In this, we see that there is an ordering of interaction through a complex set of rules formal and informal of a class described by Sapir (1967). Specifically, the virtual worlds represent a diversity of learning levels. Hence, the culture of the virtual world is equally shared among the members of the group, much like what occurs in the real world (Bailey 1983, D’Andrade 1992). The culture perpetuates itself, however, through a significant reliance on informal other-dependent learning, and the advancement of knowledge in new generations of learners. This can be explained as enculturative context (Harris 1968) affected by diffusion process (Rogers and Shoemaker 1971). This pushes forward the question, how does learning proceed among different levels of students as the students encounter each other in the virtual world? We find the answer, in part, to be connected to performative action.

In immersive virtual environments, there are performative social interactions that directly affect learning processes (Guimarães 2001). Performative interactions are social interplay that produce affects either on the performers or on the other social actors. Specifically, there is reflexive behavior as categorized by Turner (1987:81), where the student learns by observing or engaging in social interactions generated by other people. The student’s sense of self and knowledge is changed through these reflexive cognitive performative encounters. At the textual discourse level, performative behavior occurs when the students are self-conscious of their language interaction and use and perceive their role as one “to display for others” a certain grasp of other or specialized concepts and language. This is self-conscious proactive shifting of the language-style presentation of self to others (Schilling-Estes 1998:53).

For the virtual learner, performative social interaction develops and changes as the student progresses through levels of understanding and learning. These various developments are salient where the student displays increasing levels of communicative competence (similar to that described by Bonvillain 1997:247). That is, as the student expands knowledge and confidence in the information and interactions encountered in the virtual environment, the student’s learning is reflected, in part, in the ability to deal with a stylized speech and presentation forms specific to the virtual scenario discipline. Today an anthropology of performance focused on virtual environments is concerned with “the way by which the multimedia resources … are appropriated and resignified by the users through the analysis of the interactions that take place inside it” (Guimarães 2001:1).

Performance for learning is associated with studies on the cultural meanings associated to the physical behaviors of the avatars. The performance approach is related to a conception of culture as a process, a flux of facts embedded in a web of meanings that flow through time. The culture, hence, is not considered as homogeneous or fixed, but as being in continuous movement and change. Indeed, all the student’s virtual social interactions are innovations derived from the fundamental set of instructions given to the student prior to the student’s entrance into
the virtual world. However, the virtual world reflects archetypes of communication processes extant in the real world, consequently, activity in the virtual world, no matter how open-ended, will find itself reflecting hegemonic rules of interaction from the real world. Therefore, as in the real world, learning through social interaction in the virtual world is encased in rules of interaction similar to those described by Moorman (1987:459). This pushes research to ask, how does the individual’s commitment to virtual social interaction support or undermine the individual’s learning?

Furthermore, anthropologists observe that individual learning is affected by the degree of commitment of an individual to interaction with others and the environment (Morris 1994), especially interaction with change agents (Rogers 1962). Thus, in the role-based scenario of the virtual world, the amount of social role-based interaction bears on the effectiveness of the learning environment for the student. In other words, the more the student interacts with objects, agents, and persons, the more possible is engagement of other-dependent learning, and through that, diffusion of knowledge. In the authentic scenarios of the virtual world, study of learning processes affords research on the degree of commitment students have to virtual interaction with others.

**Intellectual Merit**

The theoretical and research potential of environments that have authenticity of context and relevance to real-world problems have been major themes in the cognitive and learning sciences for more than a decade. The IVEs we describe, produce, study, and assess provide an operational suite of enabling technologies for developing, implementing, and doing research that advances what is currently available in the research communities. The integrating research context encapsulates a quantitative to qualitative scope of scientific and pragmatic issues. Among the many disciplines and professions, we achieve a scientific discourse on knowledge acquisition, knowledge transfer, enculturative contexts and processes, innovation diffusion, conceptual change, attitudes and social performance, teacher education and professional development, classroom use of developed systems, and content alignment with state and national standards.

We advance our proposal based on the foundation work conducted by our team and others over the past decade. We know that students who use IVEs to learn about geology, business, chemistry, and other disciplines are doing just as well on the regular course assessments as non-IVE learners, measured in terms of performance on tests administered in the large class lecture courses. Minimally, therefore, we can argue that there appears to be no harmful impact on learning processes wrought by the IVE environment. An outcome much more scientifically significant and promising for the advancement of learning science, however, is that the students in the experimental IVE learning groups show statistically significant achievement over the level of the classroom students in the substantive categories used to measure levels of problem solving ability and knowledge transfer integration – the role-based problem scenarios (McCLean et al, 2001).

The role-based authentic problem scenario assessments are tests of knowledge transfer. The scenarios do not ask directly questions isomorphic to ones used in the virtual learning environments. There is a significant literature on knowledge transfer (e.g., Bransford et al. 1989, Brown 1989, Brown & Clement 1989, Chinn & Brewer, 1993, Gick & Holyoak 1983; Gick & Holyoak 1987; Jacobson & Archodidou 2000, Jacobson & Spiro 1995; Salomon & Globerson 1987; Spiro et al. 1987; Voss, 1987; Guimarães 2001, Dix 2000, Johnstone 2000, MacDougall 1997, D’Andrade 1987a, 1987b, 1984, 1981, Geertz 1983, Bateson 1972, Rogers and Shoemaker 1971, Rogers 1962), with the general finding of this pioneering interdisciplinary body of literature being that it is difficult to empirically demonstrate knowledge transfer after a learning experience, particularly after a relatively short learning activity treatment. We are finding alternative forms for measurement and hence are pushing the boundaries of assessment methodology for the virtual experiments (assessment is discussed in more detail later in this proposal). Given the short duration that students have so far used the IVEs (approximately 4-6 hours per coursework schedule), the significant differences in learning demonstrated between students using IVEs and those not, in control/comparison conditions, is of great scientific and artistic interest. We anticipate similar findings of evidence of learning from experience in the analyses of new data being collected in current projects. With support and funding, we can push these projects to a level that is concerned with the transactional, performative, reflexive, and recursive processes that will tell us how, in part, the learning happens.

The large experiments described in this proposal indicate that student’s virtual world experiences have a significantly positive affect on the ability of students to solve problems in the manner of scientists. They also provide evidence of the effectiveness of authentic scenario instruction and assessment. Because authentic scenario assessments are more qualitative than quantitative by nature, measuring their effects in statistical terms has been problematic for quantitative science. There is strong anecdotal evidence of their effectiveness, there is a smattering of papers conference proceedings from around the world that deal with the newest understanding of the learning
science subject, and there is a strong cross-disciplinary theoretical foundation for pursuing IVE learning practices, but there is little of what might be described as “hard data” (Jorgenson, Vanosdall, 2002). However, anthropology provides a grounding of qualitative measurement able to open up new areas of analysis and assessment.

Anthropology is both a quantitative and qualitative science. Anthropologists ask “What is this system and how does it work” and they ask “what is it like to live it”? Through strong pursuit of holistic appraisals of systems structures, functions, and processes, and through extensive reflexive interpretations and studies of cognition and meaning alongside studies of symbols and performative behavior, anthropology provides what has been described as a lateral structural language for multidisciplinary work (Gerlach 1991). By combining the quantitative methods of the statistical sciences with the qualitative methods of the social sciences, this proposal addresses the need for scientifically verifiable data that crosses multiple disciplines and the associated construction of methods and associated methodology, as well as a way to combine authentic instruction and authentic assessment with the efficiency and convenience of traditional assessments. This work will pioneer a much needed bridge between theory and practice, and has the potential to significantly impact higher learning and multiple disciplines. When we address these needs, we will have contributed significantly to the development of a more knowledgeable society able to cope with the technological and sociocultural complexities of the future.

Broad Impact

Our holistic/authentic approach to instruction and assessment, as well as the quantitative and qualitative components of evaluation, rigorously investigates students’ learning patterns and processes, as well as student knowledge acquisition, transfer, and retention. The findings from our decade of research have application beyond the borders of physical science to other disciplines and levels. Already our projects have branched out among the sciences and into the humanities at our own institution (e.g., Archaeology (Clark et al., 2002) and English (Johnston 2003)). We have established links at other postsecondary schools, as well as K-12 schools, with whom we envision solidifying partnerships upon the results of current research. We have secondary projects in development for learning in non-school situations, including proof-of-concept research focused on Native American youth, diabetes prevention and management, and the learning of dance and cultural history in a multi-user immersive physical activity virtual environment (Brandt 2003).

While our driving purpose is to advance scientific understanding of learning in IVEs, a significant expression of this purpose is to direct research that encourages the participation in disciplines of students who otherwise often are underrepresented by or mismatched with current status quo teaching methods and/or assessment methods. We will accomplish this goal, in part, through our partnership with University of Texas – Pan American. UT-Pan American is a college where 86% of the students are of Hispanic heritage. We will be able to assess how well IVEs work for this group compared to their counterparts in the traditional lecture learning scenarios. Moreover, the proposed Center addresses this research goal during the design and testing phases of the IVE by specifically avoiding approaches to instruction and assessment that have consistently been found to be unhelpful or even detrimental to these groups learning environments. For a variety of reasons simple and complex, minority and lower socio-economic student groups historically have been out-performed on traditional, standardized assessments by their non-minority, higher-income counterparts (Lomax et al., 1995). The alternative, authentic scenario approach we offer has early indications that a broader population can experience success in a multiplicity of domains (Slator et al. 1999).

The impact of our advancing research on IVE learning will be to affect the science upon which decisions for policy and education are made. By extension, our work has the potential to impact society at large, by offering new learning forms that may extend from the classroom to the school board, and from the elementary level through college. Indeed, The Center anticipates that IVEs will become a future mainstay in educators’ toolkits.

Research and Education Activities

The research aims of this center will advance an existing synthesis of theories arising in the anthropology of learning and actualized in the models and simulations of the sciences of learning. The activities of the center will be focused on the core competencies of our existing research team, which are: 1) the design and implementation of immersive virtual environments (sometimes referred to a "desktop VR") that promote role-based learning on the cognitive apprenticeship model – where students learn to think and act in a particular manner because they are trained to do so by surviving a problem-laden world (such as problems in geology, or biology, and so forth); 2) the authentic assessment of learning in these environments as measured in controlled studies through a "scenario-based assessment" methodology – an approach that quantitatively and qualitatively measures student performance in
terms of the ability to reason through domain-relevant problems; and 3) intelligent software tutors that populate the learning environments with an aim to assist students in the course of their learning experiences.

The Center we propose will build on these core competencies, and attend to all the necessary ancillary activities generated by these, by initiating outreach to a variety of collaborators both domestic and international, from industry, academia, and the public schools.

**Immersive Virtual Environments for Education**

The following describes the main development efforts of the group. This is meant to be a representative set as space does not permit a full inventory.

Without exception, NDSU immersive virtual environments are simulated on a MOO ("MUD, Object-Oriented", where MUD stands for "Multi-User Domain" – this is but one example of the economies of scale offered by our central coordination of research projects). MUDs are typically text-based electronic meeting places where players build societies and fantasy environments, and interact with each other (Curtis, 1997). 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 provide a programming language for writing the simulation and customizing the MUD. The usual platform for operating a MUD or MOO is a machine running a Unix-based operating system. Participants (usually referred to as players) connect by using Telnet or some other, more specialized, client program, which establishes a text-based session on the MOO.

**The Geology Explorer**

The Geology Explorer (http://oit.ndsu.edu) is an interface to a virtual world where learners take on the role of geologists on an expedition to a mythical, newly discovered Earth-like planet (Planet Oit). Students are given an authentic geologic goal, e.g., to locate a particular mineral found in a geologically reasonable context, or to map a metamorphic terrane. Accomplishing such a goal entails mastering several geologic concepts and procedures, and demonstrates student mastery of the material. To play the game, students are transported to the planet's surface and acquire a standard set of field instruments. They are issued an "electronic log book" to record their findings and, most importantly, are assigned a sequence of exploratory goals. 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. Students who may be physically separated by thousands of kilometers can collaborate on their exploration and problem solving. A scoring system lets student compete with each other and with themselves.

The first module, which has been tested on large (>400) classes of physical geology students, involves mineral exploration, where students are expected to plan an expedition, locate mineral deposits, and survive the somewhat hostile virtual environment in order to report on it.

![Figure: the intrusive Basaltic dike in the interpretive module](image)

**Virtual Geologic Investigation**

Geologists are engaged in the study of the materials of which the Earth is made, "the processes that act on these materials, the products formed, and the history of the planet…” (Bates and Jackson, 1984). Students can best learn geology by learning the process of geologic investigation, including taking samples, petrographic analysis of
thin sections, whole rock chemical analysis for major and trace elements, microprobe analysis of mineral grains, etc.
and by evaluating the data obtained in a theoretical context.

However, in the real world, students may not have access to all the equipment necessary for such a complete investigation, nor to the locations for collecting interesting samples. The Geology Explorer affords an environment in which expensive analytical tools can be built, and any location can be visited, virtually. A student will be able to take a sample of a garnet-biotite schist, view a thin section of it, make microprobe analyses of coexisting garnet and biotite, collect radiogenic isotope analyses, all while perhaps collaborating with a peer from a different country.

The Interpretive Module

The geologic interpretation module is based on a detailed deciphering of the geologic history of an unexplored region of Planet Oit. Because students will have already achieved several goals involving rock and mineral identification before being assigned the interpretive module, they will have the necessary background to undertake further studies.

Although apparently simple, the geology of the region holds enough ambiguity to provide training for novice geologists. While it is clear that the mafic dike cross-cuts the sedimentary and metamorphic units, features such as way-upness and the age relation between the dike intrusion and the regional tilting must be determined by careful investigation of various data types. See figure for a view of the prototype 3-D model constructed for the region.

Upon entering the region, the student is asked to map the outcrops. This requires spatially navigating the region, sampling, testing, and identifying rock types as a geologist would in the field. Some of the samples may need to be taken back to the "lab" for thin sectioning and investigation under the "microscope" (In practice these would be digital images of thin sections). As identification proceeds, the student creates a draft geologic map by locating potentially significant geologic contacts. When all these intermediate goals have been met, the student is asked to put the rock units in time-stratigraphic order. In fact, without complete information (such as, perhaps, paleomagnetic data combined with age determination of the dike), there may be more than one plausible answer. This mimics the real-world practice of geologists holding multiple working hypotheses on maps in progress (Chamberlin, 1931).

With each success, the student demonstrates mastery of the material. More advanced concepts such as thermobarometry can be learned by the student carrying out virtual microprobe analyses of minerals in the metamorphic rocks. For example they will be able to obtain microchemical analyses of garnet-biotite pairs, and together with perhaps hornblende analyses be able to estimate maximum P-T conditions to which these rocks were subjected.

Tutoring

In the field, when a student has difficulty identifying a sample, a more experienced geologist will often lead the student through a series of leading questions or provide hints on how to obtain a field identification. An important feature of educational media is this type of ability to tutor students. On Planet Oit, tutoring is done through unintrusive but proactive software agents. These agents monitor student actions and "visit" students as the need arises. Tutors give advice, but they neither mandate or insist on student actions nor block or prevent student actions. They provide assistance to players in the course of their diagnostic reasoning within the scientific problem solving required to accomplish their goals. The tutors work from knowledge of the geology, knowledge of the "experiments" needed to confirm or deny the identity of an object (e.g. contact metamorphism of limestone to marble), and the student's history.

Software and World Development

We first 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. The development of Planet Oit began with a realistic planetary design which included roughly 50 locations (arroyo, mountains, desert region, etc.), almost 40 scientific instruments and geologists tools (streak plate, hand lens, acid bottle, etc.), nearly 100 rock and mineral types, and over 200 boulders, veins, and outcrops; each implemented as simulated software objects. In the text-based version, students use a command language, which allows for navigation, communication, and scientific investigation while on the planet. Command verbs dictate the student’s application of instruments ("streak," "scratch," "hit," etc.) and senses ("view," "taste," "touch," etc.). Students can communicate, and therefore work, with one another through verbal commands.

Once the layout and artifacts of Planet Oit were implemented, the "rules of the game" were imposed over top. Specifically, we created an environment where students are transported to the planet’s surface. Students are
automatically assigned an initial exploratory goal and can acquire whatever equipment they wish. The goals are intended to motivate the students into viewing their surroundings with a critical eye, as a geologist would. Goals are assigned from a principled set, so as to leverage the role-based elements of the game. In order for a student to achieve a goal (and therefore earn points), they must address a multitude of tasks identical to those faced daily by field geologists. These include the selection and use of proper field tools, navigation across the planet to the correct region, and interpretation of the tests the student applied to the problem. As each goal is satisfactorily completed, the student is automatically assigned new goals requiring progressively higher levels of expertise and decision-making. Through this practical application of the scientific method, students learn how to think, act, and react as geologists (Dede 1996; Duffy and Jonassen, 1992).

The Virtual Cell

The Virtual Cell (http://vcell.ndsu.edu) is an interactive, 3-dimensional visualization of a bio-environment. It has been prototyped using the Virtual Reality Modeling Language (VRML) and is available via the Internet. To the students, 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 project's goals called for an interactive simulation of biological process displayed in 3D and available on the Internet to multiple simultaneous users (using low cost components). The approach taken was to build a distributed programming environment, where VRML is used for rendering and user interface computation, but where more traditional programming models can be used to perform actual behaviors. Objects on the client side, implemented in Java, are reconstructed using a VRML object, which configures itself based on parameters stored on one or more servers.

The goal in building VCell is to provide an authentic problem-solving experience that engages students in the active learning of the structure and function of the biological cell. To do this, the VCell simulation implements a virtual cell and a cell biology laboratory providing an experimental context for the student in an interactive environment. Within the simulation, virtual avatars act as guides and tutors: giving out assignments and problem solving advice. In addition, VCell is intended to support multi-user collaborations, where both students and teachers from remote sites can work together on shared goals.

The Virtual Cell is a virtual, multi-user space where students "fly" around and practice being cell biologists in a role-based, goal-oriented environment (White, McClean and Slator, 1999). Working individually, or with others, students learn fundamental concepts of cell biology and strategies for deductive problem solving through their experiences in the exploratory virtual space. This pedagogical approach provides students with authentic experiences that include elements of practical, experimental design and decision making, while introducing them to Biology content.

The Virtual Cell is populated with sub-cellular components: nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, chloroplast and vacuoles. Each structure is rendered as a 3D object using the Virtual Reality Modeling Language (VRML), a computer language for specifying three-dimensional worlds that can be displayed and manipulated over the Internet.

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 students perform simple experiments and learn the basic physical and chemical features of the cell and its components. As the project progresses, students will revisit the laboratory to receive more assignments. Periodically, the students will bring cellular samples back to the virtual lab for experimentation.

The Laboratory

The Virtual Cell consists of a VRML-based laboratory and a cell. In the laboratory, the learner receives a specific assignment (learners are always assigned motivating goals in our learning-by-doing environments), performs simple experiments, and learns the basic physical and chemical features of the cell and its components. The virtual laboratory procedures require a voyage into a VRML cell (see below), where experimental science meets virtual reality. The learners are supplied with a toolbox of measuring devices that assay various cellular processes. These tools include an O2 meter, CO2 meter, pH meter, sugar assay, protein assay, various stains and enzyme assays. As the students progress, they revisit the laboratory, bring cellular samples back for experimentation, and subsequently receive more assignments.
The Cell

Students’ understanding of the concepts related to the structure and function of the cell is an essential feature of the pedagogy of modern biology. Learning the physical components of the cell, how these components interact, and how these interactions are regulated has largely replaced the traditional organismal approach to teaching biology. The cell, though, is a complex, multidimensional environment where time and space are critical factors that determine when and where cellular events occur. It is very difficult to capture this multi-dimensionality in the 2-D space of the printed page, chalkboard, or web page.

The virtual cell contains 3D representations of all the components and organelles of a cell (nucleus, mitochondria, chloroplasts, etc). The user “flies” among these organelles and uses virtual instruments to conduct experiments (see figure). All navigation is learner directed; there is no predetermined exploratory path. This feature empowers the students to direct their own learning. The students are also able to travel into linked VRML worlds that represent the interior of each of the cellular organelles. Further experimentation inside each organelle allows the students to learn about its specific functions (Wu, 1998).

For example, the learners may confront the nucleus and perform several simple experiments. The nucleus is not consuming or generating O2 or CO2, it has a positive Fulgen stain reaction and it demonstrates a negative luciferase enzyme reaction. The learners must put these results into a context. They would have to learn from a lecture, a textbook or a tutoring agent that a positive Fulgen stain means DNA is present and a negative luciferase reaction means ATP is absent. In the cell, this general information is contained in the 3D representation and offered via touch sensitive points. Putting this and information from additional experiments together, the learner should deduce that the object is the nucleus and that DNA is contained there. Additional pertinent data about the nucleus and other cellular organelles can be collected in the same manner.

More advanced levels of the Virtual Cell include the introduction of cellular perturbations and the investigation of the functions of various cellular structures or processes. In the second level, the simulation changes the cell by either introducing a mutation or adding an inhibitor that disrupts a cellular process. An alarm sounds,
some cellular process will malfunction, and the learner will be given the goal of diagnosing the problem. Using the same tools as in the previous level, the learners will navigate through the cell, make observations, and perform measurements and experiments. The learners attempt to identify the affected area, the perturbed process, and the nature of the mutation or inhibitor that is causing the problem. As a result, the users learn details of cellular processes and functions and become familiar with the importance of various mutations and inhibitors for cell biology experimentation.

In the third level of the Virtual Cell, the learners are given a set of goals to investigate a specific cellular structure or process. They have at their disposal the tools from the first level and the mutations and inhibitors from the second level. Using these in various combinations, the students form hypotheses, design experiments, and employ the toolbox items to perform these experiments. For example, the learners might be given the goal of determining how a membrane vesicle buds off from one compartment and is specifically targeted to fuse with another compartment. Using the tools from previous levels and their experience with designing and performing experiments, the learners could determine that proteins from two compartments recognize each other, bind in a specific fashion, and promote the fusion of a vesicle to a target compartment.

The Virtual Archaeologist

The premise of the game incorporates “time arcing device” that allows players to travel back in time. They are told that an extremely important Native American site was destroyed in 1954 by flooding caused by the construction of a hydroelectric dam. This site is a potential source of invaluable anthropological and archeological knowledge, but only limited archaeological excavations took place at the site. The student assignment is to go back to the site and assist the archaeologists of the 1950s in interpreting the data gathered. They can also apply modern methods to aid in their interpretations.

Virtual Archaeologist is being developed in a game-like format in order to engage students more effectively. A player travels from one level to another, navigates through the virtual site, and visits earthlodges (not all of them will be activated for entry), the fort or its rooms, different activity areas, (such as food preparation areas, a hide-tanning spot, etc.). Or, the player may wander down to the gardens to view the crops and how they are grown. Within a given earth lodge, players is able to scan around the room, viewing the architectural elements and objects within the scene. Players are able to click on many of these objects to bring up new viewing screens wherein the objects are shown in larger scale as 3D models that can be manipulated and examined from all perspectives. By clicking on identified hotspots, the player is able to open new windows with a variety of textual information about an artifact or activity, and they are directed to bibliographic information for further research. Information will also be made available on what is real and what is speculation for a given object or activity.

When the student players arrive at the site in 1954, they are greeted by a software guide who will give them instructions throughout the game. The players are told where to go and what to find out. The guide will point out what sources of help and information are available in the system and will describe the virtual tools and instruments the students have at their disposal. In addition to locating the feature or artifact they have been assigned, the students are asked to describe and interpret what they have found. Students are also advised that software tutors will visit them if they are stuck or need help providing their answers. Periodically, the students can activate their time-arcing device, allowing them to visit the site as it was a century earlier. Once the students complete their first goal, they are immediately assigned another one. In some instances, students will also be provided with interpretations of similar features or artifacts published by an eccentric archaeologist many years previously. The students will be asked to assess the validity of those interpretations against their interpretations of the archaeological data, as well as their observations back in time. The interpretive goals will increase in complexity as the game progresses, eventually leading to interpretations of more abstract socio-cultural phenomena (e.g., religion).
Though the importance of the Fishhook site is clear, what is not clear is how it can be most effectively used as a teaching tool. Given its inaccessibility, how would faculty go about using it to teach their students the practice of archaeology (or anthropology, or history, or creative writing)? This is where traditional pedagogy fails and where immersive technology, with its emphasis on student problem-solving, shines.

Teaching the principles and reasoning of archaeology through the use of problem-solving exercises is an age-old pedagogic method. For decades, some archaeology faculty have used text-based problems wherein students are given a set of data and are required to answer questions or “reconstruct” a site by applying what they have learned to the available data. Sometimes these problems are based on real sites and data, while other times they are fictitious. Books are also available that present interpretive and/or methodological problems (e.g., Daniels and David 1982; Patterson 1994). The application of computer technology has also been used for teaching archaeology. As long ago as the mid-1970s, for example, Dr. David Grove at the University of Illinois used the Plato computer to create a digital excavation, although it was largely a text-based effort. More recently, commercial programs and user manuals have been available, for example Adventures in Fugawiland (Price and Gebauer 1997), Virtual Dig (Dibble et al. 2000), and WinDig (Campbell 1996).

The problem-oriented approach is excellent for teaching critical thinking and analytical skills, although the works mentioned above have weaknesses. For example, such efforts often do not provide a great deal of real domain content (Dibble et al. 2000 is an exception). Moreover, even the computer-based projects use unsophisticated technology; lack 3D graphics, are not immersive, and are limited in interactivity. Yet, archaeological excavation is inherently spatial. The spatial distribution and relationship of the different material traces of past life is critical to the enterprise, and that spatial quality cannot be easily expressed or understood in a strictly 2D world. Therefore, the computer-based projects currently in use cannot provide students with an accurate archaeological experience. In fact, true virtual archaeology – that is, not just text and illustrations viewable with a computer – has rarely been used effectively for teaching archaeology (Sanders 1997).

The project discussed here differs significantly from previous efforts with computer-based approaches by creating a 3D, immersive, virtual-reality re-creation of an actual site. That site is the Like-a-Fishhook Village, later known also as Fort Berthold. This will be a dual-level environment representing the identical place at different times. The primary level will depict the site as it existed circa 1954, when it was undergoing excavation. (For pedagogic convenience, all excavation, which in reality took place over a four-year period, is condensed virtually into a single season of work.) The second level will virtually recreate the site as it existed a century earlier (ca. 1854). Student users will be able to do what every archaeologist has dreamed of: travel back in time and see how artifacts were used, what soil features really represent, what activities actually took place at a specific location, and much more. Through the use of authentic environments, students can jump back and forth through time, from excavation evidence and lab analysis to the past where they can check their conclusions. They will be able to interact with these objects in their cultural – albeit virtual – context.
The virtual Fishhook site thus possess a critically important feature that enables all problem-solving projects to be effective in reaching students: it will be interesting. It is our contention that those books and CDs that exist are not as engaging as they could be. They are either too simplistic or too intent on teaching archaeology methods more in line with advanced undergraduates rather than beginning students. While we fully intend to teach archaeological methods, the Virtual Archaeologist will teach scientific methods and critical thinking in a way that is much more broadly applicable. In other words, this learning experience is designed to go beyond teaching domain-specific content.

While it will, indeed, go beyond its specific domain, we decided to base the immersive environment on an actual site rather than invent a site. Two factors figured into this decision. First, even though we are designing the game explicitly to teach students how to think like archaeologists, there are other domains of learning that will be incorporated through the use of an actual place and time. Virtual Archaeologist will also provide a learning environment for cultural anthropology, as students come to understand, for example, how a tobacco pipe or house alter fit into, and informs us about, the belief system of a group of people. We are also creating an environment in which students will virtually experience a significant period of American history. Students also will be exposed to information and techniques in ethnohistory, Native American Studies, and culture change. Additionally, we plan to make the virtual environment available as a platform for developing historical fiction. Initial development of this application will be conducted by English faculty at NDSU in conjunction with Fort Berthold Tribal College.

Second, we are involving local organizations in this project. We plan to use the virtual Like-a-Fishhook/Fort Berthold Village (without the game component) in an interactive display at the Heritage Interpretive Center in Bismarck, North Dakota – the museum of the State Historical Society of North Dakota (SHSND). That display will be part of a new, permanent museum exhibit entitled “Era of Change.” The theme of that exhibit is the changing conditions in the Northern Plains, with a special focus on the impact of European Americans on both the natural environment and the resident Native American populations. This exhibit will include digital 3D models of various artifacts as well as the virtual Village. Through this virtual exhibit, the museum can display, at a kiosk or large screen, a much larger portion of their collection than otherwise exhibitable, and it can display those objects in a stimulating visual context (see Kerendine 1997; Kadobayashi et al. 2000; Purcell 1996; Russo 1998; Terras 1999).

The ProgrammingLand MOOseum

The ProgrammingLand MOOseum (Hill and Slator, 2000; Slator and Hill, 1999) 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++. Student visitors to the MOOseum 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.

There are two MOO entryways. The first leads to a series of rooms that describe the basic commands of the MOO. The other leads to the Language Foyer which leads the student to one of several “lessons”. Each of these lessons may lead to one or several further lessons. A lesson is an amount of instruction that could reasonably be completed in one sitting, whereas a topic is usually several lessons and hence too large for a single session. It should be noted that both lesson and topic are arbitrary terms without specific boundaries in the MOO. If a student wants to learn one lesson in several settings, they have the freedom to progress at their own pace in whatever way they choose. Thus, students do not perceive lesson boundaries or topic boundaries. All they see are single exhibits, which are single rooms and the brief amount of information that is present in that context.

A single exhibit will convey a very limited amount of text. This text may be any of several types. One common exhibit is a signpost. A signpost exhibit does not convey much technical information, instead it is usually the entrance to several other lessons and topics. The C++ Foyer is a signpost directing students in any of several directions. The figure shows the Function Lesson which is a signpost exhibit and an example of what a touring student would actually see in this lesson:
Function Lesson
This is the start of a number of lessons about functions.
Consider the following menu that may be selected by letter or topic:
   a) The importance and usefulness of functions (why)
   b) Using functions or calling functions (call)
   c) Overview of function definition (define)
   d) Function parameters (parms)
   e) Function return values (type)
   f) Function and variable scope (scope)
You may choose any of these and enjoy.

Figure: an example of a Signpost Room

The first line “Function Lesson” is the MOO room name. The next ten lines are the room description. The last four lines are a listing of the exits from this room. This description as a signpost does not convey any significant technical information, but does direct students to a series of lessons. This particular signpost is arrayed like a menu. A student may type either “b” or “call” and go to the same room. The name of the room is given when the room is created. The description of the room is written after the room is created and is the main means of conveying information. The last four lines are generated by the MOO server to indicate the available exits. Each of these exits may have one or more synonyms that cause the student to progress to the destination room.

The most common type of exhibit is informational, a room where some content is given. This can take any of the forms that a lecturer would use. For example on the menu shown in the figure the first option is mostly motivational – why is this feature useful to the student. In an actual lesson this is needed to pique the curiosity or otherwise show the need of the concept about to be discussed. Lecturers do not need to motivate the good students, but a lesson has to be inclusive, so motivational comments are required. Yet in the virtual lesson students may pick and choose what they view and in particular a student may skip the first part of the function lesson if they desire. Other rooms may have the informational content of other parts of a lesson: simple descriptions, a variety of longer descriptions and examples. No oral lecture can have the number of examples of a virtual lecture since the student does not need to view them all, only enough to grasp the concept.

The MOO attaches to each student a list of exhibits they have visited. This list of exhibits is available to the instructor and is a record of progress and a diagnostic tool for that student. This list cannot consider comprehension, but does demonstrate exposure. For distance learners it is a concrete measure of activity for a student that may have no other communication with the instructor. A student who has a problem, may just have missed the part of the Virtual Lesson that dealt with the item in question, so that an obvious course of remediation can then be suggested.

This history of exhibits also enables an improvement to the structure of the museum. In order to keep the hypertext reference document convenient many more paths must be created than a novice should be allowed to use. Designing a Virtual Lesson requires a balance between the single linear path, which penalizes advanced or returning students, and the potential for too many choices which invites the novice to exhibits where they are more likely to be confused than educated. The solution to this dilemma is the active exit.

The active exit checks the prerequisites for the room. A student taking a path to an advanced topic has their history checked against some possible background exhibits. If the student has visited rooms that form the foundation for the room to be entered, they are allowed in without knowing that their prerequisites have been tested. If they have not visited the rooms needed then the exit suggests that this room may be more confusing than helpful and asks them if they really want to proceed. An advanced student may have acquired the needed knowledge outside the Virtual Lesson and thus can go forward, while a merely curious novice has been warned and at least knows there is potential confusion ahead.

A very important consideration for any educational tool is the interest level that the tool maintains in the student. Consider public libraries: most of those that lend video tapes are actually lending more tapes than books, which is especially remarkable when considering the selection of book dwarfs that of video tapes in most libraries. The implication is clear, video tapes are more engaging than books. Similarly, the Exploratorium model for a museum is more interesting than the older museums with glassed in exhibits and no interaction. If interest level was not a consideration we would write good textbooks, hand them to the students and administer examinations at the end of the time. The impracticality of such an approach is obvious. A web implementation of the reference document will hold a student for a while, but will eventually become essentially the reading of an electronic text. What is needed is something even more interactive than the reference document or even the Virtual Lesson possible
in a MOO. This is accomplished by software agents. Such agents may appear as a code machine that occupies the room and has various commands that operate it. It may also be a robot, that the student might or might not distinguish from another student, who comes alongside and questions or tutors the student as they walk through the museum.

Software Agents and Intelligent Tutoring

Agents, and especially intelligent, adaptive software agents, are a necessity in the kinds of self-paced anytime/anywhere environments we propose. At NDSU we have developed a taxonomy of atmosphere, infrastructure, and tutoring agents (Slator 1999).

Atmosphere agents lend color to simulations. They do not directly effect game play but provide animation and interest without causing distraction.

Infrastructure agents provide services for game play. They are necessary to the simulation in some way, and are often the basis of the simulation.

Tutoring agents observe student actions and intervene at strategic points. There are a variety of strategies employed: simple rule-based triggering, diagnostic interventions prompted by student errors (Slator 1999), and case-based interventions that rely on a library of past cases and classifications of student tasks and errors (Regan and Slator, 2002).

The overall goal is focused on developing and employing intelligent agents within multi-user distributed simulations to help provide effective learning experiences. From the perspective of intelligent tutoring systems, the agents of interest must fundamentally support models of the knowledge of a domain expert and an instructor. However, it is desirable that the agents have a number of additional capabilities as well, including awareness and understanding of other agents in the simulation. Some of the desirable intelligent agent capabilities are as follows:

1. Intelligent interaction among agents, including both collaboration and competition to achieve goals. This requires tracking (monitoring) the actions of other agents, assessing their goals and reactive behaviors, and inferring their states and plans over time. In general, the plans need not be rigidly prescribed, but can rather dynamically respond to changes over time.

2. Mechanisms for analyzing successful decisions, in order to recognize relevant features, and to support the explaining of their reasoning to learners. This may involve such things as episodic memory for recalling previous decisions and the circumstances under which they were made as well as a structured decision analysis capability for determining which features are relevant.

3. The ability to monitor, recognize and anticipate when the student reaches an impasse situation, in which progress toward successful completion of task is stymied.

4. Explanation facilities, including answering questions about why tasks should be performed in a certain way, and the ability to “walk through” or demonstrate how to perform tasks.

All systems of multiple software agents, including those created for pedagogical purposes, must be provided with the ability to communicate with their peers through the exchanging of messages, usually expressed in an Agent Communication Language (ACL). Typically an ACL will provide for the communication of such things as constraints, negations, rules, and quantified expressions. There are a variety of approaches to providing an ACL, and there are also dependencies on communication and interoperability standards such as CORBA and OLE (Mayfield, et al., 1995). There are key issues involving the semantics of specifying such things as preconditions, post conditions, and satisfiability; network transport mechanisms, security and authentication (Genesereth and Ketchpel, 1996).

There are several alternative means of designing and developing agent architecture, and they differ in their appropriateness for pedagogical applications. One type of approach employs direct interagent communication mechanisms, and all agents handle their own coordination activities. For example, in the contract-net approach (Davis and Smith, 1983), agents distribute requests for proposals to other agents, who respond with bids to the originators, who may award contracts for services. Specification-sharing approaches involve agents advertising their capabilities and needs, which are then employed by other agents. A competing approach organizes the agents into federated systems, generalizing the concept of a mediator (Wiederhold, 1989). A federated system uses facilitators to perform intermediate brokering functions and transfer of messages, eliminating direct agent-to-agent communication.

Assessment of Student Learning

We have pioneered scenario-based assessment research to gauge whether students are learning in immersive virtual environments. In its simplest form, scenario-based assessment poses an authentic open-ended,
commonplace problem-solving situation, and asks for a solution, as well as a list of questions relevant to the problem. These responses are evaluated, according to a pre-determined protocol, by content experts looking for evidence of problem solving technique and intuition. The scoring protocol stresses the importance of reasoning over the recitation of facts. We use these instruments in controlled studies that contrast experience in our virtual environments with a variety of alternative exercises, in order to determine what students are gaining from the various treatments. We propose to engage in a range of activities designed to further our understanding of this form of assessment. Among these, we will develop intelligent software to simulate interactive interview situations, with an aim to determine what makes scenarios effective, and what makes for a good scenario.

Scenario-based assessment of student learning has long been a part of formal educational evaluations. Historically, scenario-based assessments have taken various forms. For instance, some mathematical word problems, open-ended questions at the end of history textbook chapters, and writing prompts for English exams have scenario-based components. More recently, scenario-based assessment tools have been employed in teacher education programs, wherein pre-service teachers examine a situation, its components, and arrive at possible solutions to the scenario in a web-based medium (Williams and Williams, 2000). Scenario-based assessments have likewise been effectively used in environmental geoscience in-services for middle school and high school teachers (Cooper, Shepardson, and Harber, 2002). Vocational-technical schools have also adopted scenario-based assessments, using workplace-derived measures of competent performance to teach and assess students (Losh, 2000). Such performance-based assessment been a part of medical education for many decades: and, beyond the educational setting, scenario-based assessments are used for training by the FBI, major business corporations, and multiple crisis management organizations (Swanson, Norman, and Linn, 1995).

The attraction to such assessment is its effectiveness. Employing scenario-based assessments helps to better insure that students are not feigning competence: there is little separation between “test performance” and real learning (Shepard, 2000). Scenario-based assessments are a part of a larger category of evaluation called “authentic assessment,” which means that student performance on intellectual tasks is directly examined (Wiggins, 1990). Students benefit in having the opportunity to engage in authentic work and receive feedback that speaks directly to their capabilities as scientists, historians, and so on. Additionally, the exploration of in-depth situations encourages students to develop problem-solving and higher-order thinking abilities (Lockwood, 1991). The advantages of using scenario-based assessments include: 1) Comparing performances of students against actual roles and tasks, 2) Providing a quantifiable score that is easily understood and communicated, and 3) Employing a structured/logical approach that can be equally applied.

**Assessment Results**

All WWWIC assessments are based on the idea of authentic assessment (Bell, Bareiss, and Beckwith, 1994), within authentic contexts, where the assessment goal is to determine the benefit to students derived from their "learn by doing" experience using our virtual environments. Our scenario-based assessment protocol is a qualitative one that seeks to measure how student thinking has improved.

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 measure of their progress.

In addition to these outcome-based measures, all students are asked to answer open-ended scenario-based questions before and after the experiment. These scenario questions are word problems that present the student with a situation that a scientist might be confronted with (the complete set of Planet Oit scenarios can be viewed at http://oit.ndsu.edu/~mooadmin/PLANET/assess-scen.html). Students respond to the question with a narrative answer, which is evaluated according to an established protocol.

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 day's 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.

Geology Explorer Experiment Results
Students were divided into three experimental groups: two groups completed a self-evaluation in which they rated their abilities and experience working with computers and computer software. These were asked to experience Planet Oit or an alternate internet-based activity equal in estimated time-on-task; a 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, looking for evidence of improved performance. If players score better on the problem solving scenarios, this creates the clear implication that they have learned from the experience. Analysis of the data shows that students who 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.

Table 1. Performance results of 1998 Geology Explorer experiment.

<table>
<thead>
<tr>
<th>Group</th>
<th>Group size</th>
<th>Pre-experience mean score</th>
<th>Post-experience mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>161</td>
<td>9.3a</td>
<td>25.6a</td>
</tr>
<tr>
<td>Alternate</td>
<td>95</td>
<td>8.5a</td>
<td>24.4a</td>
</tr>
<tr>
<td>Geology Explorer</td>
<td>78</td>
<td>6.8a</td>
<td>35.9b</td>
</tr>
</tbody>
</table>

F = 0.094  F = 6.320  P = 0.393  P = 0.002

Scores were evaluated using a one-way analysis of variance and the Duncan’s means separation test (Table 1). No significant difference (P = 0.393) was detected among Pre-experience group means. In contrast, Post-experience group means demonstrated a significant difference (P = 0.002). Among these means the Post-experience mean of the Geology Explorer group was significantly higher mean test score than the other two groups.

While a few others have shown significance in controlled studies over the years (e.g. Huppert et al., 1998; Mestre et al., 1992; Van Haneghan et al., 1992), this is the first where significant improvement in student learning provably resulted as a direct consequence of student use of an immersive (and self-paced) virtual environment, without direct intervention from a teacher or indeed any additional classroom experience at all.

Virtual Cell Experiment Results
To test whether users of the Virtual Cell have an increased ability to solve cell biology problems in a manner reminiscent of a professional in the field of cell biology, we collaborated with instructors teaching the large enrollment General Biology (NDSU Biol 150) class during the fall semester, 1999. General Biology is an introductory course for science majors which concentrates on cellular and molecular biology, genetics, and evolution. Students were recruited to the experiment by offering them the opportunity to earn extra credit points. As in the Geology experiment, two groups were matched to ensure equal distributions of technological ability. The volunteers were assigned to the Virtual Cell and Alternate experimental groups so that computer literacy was equal for both groups. Those students who did not volunteer formed the Control group which did not participate in any activities beyond normal lectures and labs.

Members of the Virtual Cell experimental group completed two Virtual Cell modules. The first module, *Organelle Identification*, was completed at the beginning of the semester. The second module, *Cellular Respiration*,
was completed six weeks later. Students were given ten days to complete each module. Student progress through the modules was followed by a game-like point scoring system.

The alternate group was included to serve as a computer-based, time-on-task control. Students in this group were sent to a series of WWW sites that contained content material similar to that offered in the Virtual Cell modules. Participation was monitored by completion of an on-line quiz. Each quiz was evaluated to determine the student made an "honest effort" to study the WWW sites. Specific questions were included that could only be answered if the student visited the site.

All students, whether in control or test groups, were asked to complete two scenario-based questions at the beginning of the semester, before their Virtual Cell or alternative assignments. One question asked them to act as a cell biologist and design experimental approaches to solving a problem in which they must distinguish between cellular organelles (figure 2). The second question tested the students' ability to determine experimentally why reactions related to mitochondrial electron transport were not functioning properly. Similar scenario questions were given to all students at the end of the semester. 332 of the students answered both the pre and post questions.

You are on a foreign fellowship to work with Dr. Larsson in Sweden. Dr. Larsson is a cell biologist who specializes in human diseases. A new group of patients arrived recently exhibiting myopathy, a severe muscle weakness. The most prominent symptom is the severe muscular weakness that occurs after only a short period of exercise. Using his vast experience with cellular diseases, Dr. Larsson immediately suggests the Golgi apparatus is not functioning properly. This strikes you as not quite right. You suspect another organelle is not functioning correctly. You quickly volunteer to test Dr. Larsson's hypothesis.

While thinking as a biologist, list the things you will consider when designing your experiments. Briefly describe the experimental results that will allow you to determine which organelle is not functioning properly.

Table 2. Mean and F-probability for the 1999 Virtual Cell experiment.

<table>
<thead>
<tr>
<th></th>
<th>Organelle Identification Module</th>
<th>Cellular Respiration Module</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test Scenario</td>
<td>Post-test Scenario</td>
</tr>
<tr>
<td>Control Mean*</td>
<td>11.5a</td>
<td>17.4a</td>
</tr>
<tr>
<td>Alternate Mean</td>
<td>13.5ab</td>
<td>19.7a</td>
</tr>
<tr>
<td>Virtual Cell Mean</td>
<td>15.5 b</td>
<td>22.7b</td>
</tr>
<tr>
<td>F-probability</td>
<td>0.005</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>0.431</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Population sizes are: control=145; alternate=94; and Virtual Cell=93.

This large experiment clearly demonstrates that the Virtual Cell experience has a significantly positive effect on the ability of students to solve problems in the manner of a cell biologist. The fact that the Virtual Cell group mean value is significantly higher than the Alternate group strongly suggests the improved ability is not simply the result of computer-based time-on-task, but rather is directly related to the Virtual Cell experience. This is encouraging because the experimental effect is identical to that observed with the Geology Explorer.
Task Modeling and Data Mining

While the educational benefits of role-based learning have long been observed anecdotally quantitative methods of evaluating their dynamics have only recently become available. Role-based Immersive Virtual Environments present a unique opportunity to study social networks and gain insights that can help improve the environments themselves as well as our understanding of social networks in general. The data mining and knowledge discovery community has recently experienced a surge of interest in social networks. The KDD-cup 2003, a data mining competition in conjunction with the ACM conference on Knowledge Discovery and Data Mining explicitly addressed this topic (Ginsparg, Gehrke, and Kleinberg, 2003). Whereas structural issues of social networks have been investigated for some time (Barabasi and Bonabeau, 2003) much is still to be done to understand patterns within the data that are associated with individuals who are part of the network. So far work has largely focused on prediction tasks (Getoor et al. 2001). Our work has a particular need for characterizations of the students’ learning behavior as they interact with their peers within the virtual environment. We expect to find different types of students, some who benefit from the exchange of ideas, some who get motivated by the presence of friends, and maybe some who get distracted by too many interactions. Knowing the different roles students have in their peer communication and evaluating their impact on student performance will help us encourage productive collaboration through the design of our environments.

Virtual environments provide insights into more than one aspect of student learning. Never before has so much data been available, telling us about steps students take on their way towards understanding of a new subject matter (Slator, Saini-Eidukat, Schwert, 2001). Detailed sequences of actions are ready to be analyzed for patterns that characterize a particular student or a particular environment. Patterns from sequences form a new building block in the characterization of student behavior adding to traditional properties such as average use of resources that are available to students within the environment (Regan and Slator, 2002). Clustering techniques allow the identification of typical examples of student behavior that are valuable for the design of software tutors by means of case-based reasoning techniques. In particular hierarchical clustering techniques that provide detail at different levels of granularity add a new dimension of fine-tuning to the area of case-based reasoning.

Student behavior is not static. We hope that the guidance we provide will help students acquire expertise and decision making skills that will affect their behavioral patterns. This time dependence is fundamental to our analysis goals and adds further challenges to the data mining processes we plan to develop. Incorporating time-dependent features into both network-oriented and sequence-based analysis can be done at any point of our work. Simple strategies exist that allow drawing conclusions based on samples taken at different stages in the student’s learning experience. We plan to develop new techniques that account for continuous changes wherever the benefits outweigh the extra effort.

Collaborative Learning

While constructivist theories tend to emphasize individualized understanding of content, modern trends in education, most notably workforce training, is firmly committed to cooperative and collaborative learning. IVEs, being multi-user systems, logically support such approaches. New systems for dynamically formed exploration groups are being developed where learners are matched for joint task assignments and learning goals within IVEs.

Systems and Tools

A range of tools have been developed to assist with the construction of role-based IVEs. These mainly include graduate student projects resulting in systems for creating simulation structures, developing agent-based conversation networks, and Java-based client software for visualizing and editing simulation objects.

Another major effort has been the design and prototype implementation of the JavaMOO project. JavaMOO is a MOO written in Java. The intent is to create implementation and associated software libraries that provide order of magnitude improvements in the scaling and performance issues related to LambdaMOO.

Lastly, it turns out that hosting immersive virtual environments for education in a robust and consistent way entails a significant effort devoted to the online systems that users expect. This need is complicated by a project’s need to arrange studies, construct balanced treatment groups, permit faculty access to student records, and a host of other IT functions necessary to mounting an operation of this type. We have a continuing commitment to developing support systems for managing users and experimental data based on the LAMP suite (Linux, Apache, MySQL, and PHP or Perl). Our efforts in this arena have resulted in a system with commercial possibilities (Opgrande et al. 2002); refer to the section on sustainability later in this proposal).
Education and Outreach

A primary strategy of the new center would be to involve students in ways more extensive than currently possible. These would include not only on-site research, but also remote research and student program exchange. Students with an interest in IVEs as vehicles for learning would take courses directly addressing IVE as a science of learning discipline. For example, Dr. Slator teaches a course on Virtual Worlds for Education. The purpose of the course is to study the theory and practice of role-based immersive virtual environments in a context of a science of learning. We would implement a series of seminars and courses for students interested in the science of learning in IVEs. However, we have determined that it is premature at this time to develop a terminal degree graduate program specializing in IVEs. The literature and research are yet scattered. However, by the end of its first five years, when the Center has achieved its goals of organizing the body of research currently available on IVEs for education, we anticipate constructing a terminal degree program on the core competencies of our various researchers.

The life-cycle of role-based IVEs is essentially the same as any software product: design, implementation, testing, rollout. The primary NDSU innovation is in the rollout strategy which employs courses and course development for domain area teachers. These courses take the form of hands-on workshops that train teachers to use the NDSU systems and develop lesson plans for their classrooms. The syllabus for a course offering, Summer 2003, is online at http://wwwic.cs.ndsu.nodak.edu/biol-geol-600/. We have primarily conducted this education and outreach during the summer, but with the Center, we could extend this to a year-round activity.

The E-Journal of Immersive Virtual Environments for Education (e-JIVEE)

While there is a growing body of published work on IVEs developing around the world, there exists no centralized publishing forum specific for immersive virtual environments for education (IVE) scientists. The closest thing, the online Journal of Virtual Environments (JOVE) at http://www.brandeis.edu/pubs/jove/ is described by the editor (David Jacobson, personal communication) as “quiescent” and likely to become a series of occasional papers. Otherwise, papers and project presentations are scattered across journals and conference proceedings published by many disciplines, from the health sciences through computer science to philosophy and the social sciences. The pioneering scientific and social relevance of a science of learning in immersive virtual environments for education demands a central location for research review and dissemination. The e-Journal for Immersive Virtual Environments for Education (e-JIVEE) will be the premier peer-reviewed electronic journal for peer dissemination of the Center’s research work and the work of other international scientists, scholars, and artists involved in immersive virtual environments for education.

The e-JIVEE editorial policy will demand that the published research meet the most rigorous standards of scientific and social responsibility. A contributing editorial board will be established and include international professionals from across the sciences and humanities as well as the public sector. This e-Journal will publish basic and applied scientific, humanistic, and other forms of critical work focused on learning in IVEs. Additionally, the e-Journal will include viewpoint papers, a column for futures discussions, a section on projects currently underway at various institutions and organizations, a section devoted to training and education of future IVE scientists, a section devoted to visual art, performance, and learning, and a section for policy and private sector implications. Furthermore, the journal will encourage publishable replies to critiques of e-JIVEE published work and will host scheduled online research forums as needed by Center researchers.

We propose an electronic journal and not a print journal because of the nature of our subject. By virtue of being an electronic medium, the e-JIVEE will incorporate in its publication supporting visual materials not typically found in print media, including audio, stills, video-streaming, slide-shows, associated Internet links, and other electronic visualization tools. The content of the e-Journal will be of interest to scientists, scholars, students, virtual artists, policy-makers, private sector businesses, K-12 teachers, and college instructors concerned with research, implementation, assessment, and policy decision-making associated with a science of learning in immersive virtual environments. E-JIVEE will be published quarterly beginning with a premiere issue early in the first year of the Center that will focus on the inaugural work occurring at the Center. The journals’ outcome will be a central peer-reviewed stage for engagement of IVE scientists and scholars in a dialogue of pioneering research that will open up new frontiers of a science of learning in immersive virtual environments.

Complementary Activities

While the Center will concentrate on core competencies, there is a range of activities planned under a number of headings: partners, collaborators, sponsors, and clients.
Partners

Partners provide opportunities that are not available locally. In particular, partners provide the means for testing software and gathering data. We have long maintained links to institutions with strong traditions of teaching, mentoring and workforce development; in particular, we have past and current research projects underway at Minnesota State University Moorhead, Concordia College (Moorhead), Valley City State University (Chaffee 2000, 2001), Minot State University (Markell and McKenney, 1999, McKenney 2000), and the two year colleges, the United Tribes Technical College (Derby, 2001), Fort Berthold Community College, and the North Dakota State College of Science (West 1999). We are currently arranging studies at Youngstown University in Ohio and the University of Nebraska – Lincoln.

Collaborators

We propose a summer faculty/student exchange program that will start with seminars and lead to joint projects. We have agreements in place with the following institutions.

The Department of Technology Education and Digital Systems at the University of Piraeus in Greece offers a degree course specializing in educational technology and houses an active research environment. This provides an international component.

The United Tribes Tribal College, a tribal college located in Bismark, North Dakota, is part of our funded ProgrammingLand MOOseum project which studies virtual computer science education. This provides a tribal college component. In addition, we have developed a relationship with the White Earth Tribal Health Center, originally to propose a diabetes education project to the National Institutes of Health (NIH).

The Center for Distance Learning at the University of Texas – Pan American located in Edinburg, Texas, is a predominantly Hispanic institution that has promised to develop joint projects and a faculty/student exchange program leading to joint development projects relevant to them.

The importance of these diverse collaborators lies in the cultural diversity they provide. Since our arguments rest on a notion of learning as immersive enculturation, it becomes important to study how different underrepresented cultures (Native American and Hispanic, in our case), respond to the enculturation opportunities provided by our systems. Is it possible that our immersive approach provides an alternative modality that is more available to diverse real-world cultural groups? This warrants study, as implications reach to scientific questions of pan-human knowledge acquisition and policy questions on education and empowerment (Brandt 2003).

Corporate Affiliations and Sponsors

Alias|Wavefront has provided licenses for it’s Academy Award winning 3D development software, Maya, for several years and most recently has offered the group a set of tuition waivers for Maya training.

Yumetech Inc. has worked closely with us on developing a new standard for Java3D. They are the leasing open source developers of 3D solutions and have been working to our specification to bring our systems into the mainstream.

Clients

The culmination of our graduate level course offering in Immersive Virtual Environments for Education has been the introduction of our systems into K-12 classrooms. The Geology Explorer and the Virtual Cell are being incorporated into the curriculum at 23 schools in North Dakota and Minnesota as a consequence of our course offering during the summer of 2003, mentioned above. This is just the beginning, as we have plans in place to extend this to other venues in the coming years.

Management Plan

The scale of the research involved to understand and advance our knowledge of learning in IVEs requires a complex lateral and vertical aligning of various scientists, institutions, and private sector groups. Primary outcomes of research – the advancement of a learning science – will intrinsically develop secondary outcomes for student education and training, and public-private partnerships, that will make the work of the Center as a whole greater than the sum of its parts. We can establish such wide-reaching and multiple level outcomes by developing from our current footing as the North Dakota State University (NDSU) Worldwide Web Instructional Committee (WWWIC). WWWIC is a core group of multi-disciplinary faculty with connections to industry, community, and publics dedicated to research and development of Immersive Virtual Environments (IVEs) for Education. WWWIC is a
consortium of Anthropologists, Archaeologists, Artists, Biologists, Computer Scientists, Education specialists, English faculty, Geologists, Plant Scientists, and Social Scientists.

WWWIC first formed in the mid-1990s as a service to the NDSU institution but quickly turned to research oriented activities and the construction of innovative role-based educational environments. At first, this was a grass-roots effort staffed by interested faculty and student volunteers who were intrigued with the ideas and the fundamental appeal of educational games, mostly, in the faculty cases, working on faith, and in the student cases, working for extra credit or independent study. Those were exciting times, where ideas were worked out and implemented by faculty and students who were true believers.

In early 1998 the first funding was secured. This allowed the Geology Explorer (Schwert et al., 1999) and the Virtual Cell (White et al., 1999) to undergo significant development as effective, immersive virtual environments. Supported formal studies of the Geology Explorer in the Fall of 1998 showed statistically significant improvements in student learning. These results were replicated in 1999 for both the Geology Explorer and the Virtual Cell, and we were operational, able, with accumulating data, to show that our ideas actually worked and were pushing forward the frontiers of learning.

In the intervening years WWWIC has established itself with a sequence of publications and funded projects, totaling roughly 70 journal and conference papers and nearly $4 million in funding as of this writing. The group now encompasses over 50 members counting faculty, staff, graduate and undergraduate student employees.

Operations

The intellectual direction of the Center will continue to be set by the faculty PIs meeting on a regular basis as we have for the last several years. These weekly (2-hour) meetings are used to set strategy, design projects, make staffing decisions, share research results, and coordinate activities. These meetings are now a long-standing tradition with the group. Team members (faculty, staff, and students) of individual projects also meet weekly or biweekly to discuss project progress, planning, and so on.

Administration

CENTER DIRECTOR. The Lead PI (Dr. Brian Slator, Professor of Computer Science) will serve as Director of the Center for Learning in Immersive Virtual Environments and will be the final administrative point of contact. He will conduct one graduate level seminar per year to maintain contact with students and teaching, and otherwise devote himself to the research and service activities required to manage the Center. The budget reflects allocations necessary to replace his normal teaching duties.

CENTER LEADERSHIP TEAM. The Leadership Team reflects NDSU’s status as a land-grant university by emphasizing basic research and development that will impact positively the future of society through an educated citizenry. The Center’s Leadership Team is made up of scientists from NDSU’s College of Science and Mathematics (CSM), College of Arts, Humanities, and the Social Sciences (AHSS), College of Human Development and Education (HDE), and the College of Agriculture, Food Systems, and Natural Resources (AFSNR). Each team member has extensive background involvement in WWWIC and other learning sciences expertise. We will grow from this core Leadership team. Team members, in alphabetical order, are:

Dr. Lisa Brandt, Research Affiliate, Dept. Sociology and Anthropology. Dr. Brandt has been working with issues on peer-review of digital research and online publications. She will be responsible for the e-Journal as well as anthropological role-based and enculturative processes learning sciences research.

Dr. Jeffrey Clark, Professor, Department of Sociology-Anthropology, Director of the Archaeology Technologies Laboratory. In addition to the archaeology IVE projects, Dr. Clark will be responsible for managing 3-D imaging and other associated anthropology interactive learning science and data management projects.

Dr. Lisa Daniels, Assistant Professor, School of Education , Teacher Education. Dr. Daniels will coordinate the research on assessment and evaluation of student learning in the IVE projects.

Dr. Ann Denton, Assistant Professor, Department of Computer Sciences. Dr. Denton (in cooperation with Dr. Perrizo) will be responsible for the data mining research and associated tasks and projects.

Dr. Phillip McClean, Professor, Department of Plant Sciences. In addition to the Virtual Cell IVE project, Dr. McClean will be responsible for coordinating the animation and visualization learning research components of the Center.

Dr. William Perrizo, Professor, Department of Computer Science. Dr. Perrizo (in cooperation with Dr. Denton) will be responsible for the data mining research and associated tasks and projects.

Dr. Bernhardt Saini-Eidukat, Associate Professor, Department of Geosciences. Dr. Saini-Eidukat will be the principal designer and coordinator for geosciences learning research projects.
Dr. Donald Schwert, Professor, Department of Geosciences, Director of the Center for Science and Mathematics Education. Dr. Schwert will be responsible for the coordination of intellectual exchange with a broad community of users. This will include peer and community outreach, the maintenance of current partnerships, the establishment of new collaborative partnerships with various communities, and the coordination of Center research dissemination activities.

Dr. Alan White, Professor, Department of Botany/Biology. Dr. White will be the principal designer and coordinator for biological sciences learning research projects.

PROJECT TEAMS The individual teams that make up the core Center activities varies according to specific project need, but at a minimum, each team is made up of women and men faculty, graduate students, and undergraduate students representing a variety of major, minors, and terminal degree programs at NDSU. There will continue to be proactive recruitment of students from underrepresented minorities and other groups often not found in scientific teams, including those with special needs. Additionally, students involved in exchange programs (for example, the Center’s planned exchange program with the University of Texas Pan-American and the University of Piraeus, Greece, and current partner institutions in the region, including the tribal colleges) will participate as valued members on various teams. With the mixture of cultural backgrounds and experiences, ages, professional skills, and scientific experience, each project team is able to address more holistically the primary problems of learning specific to their disciplines and the goals of their project.

CENTER BUSINESS MANAGEMENT The Center will require the following professional positions to run the daily management activities: Administrative Assistant to the Director, Center Fund Writer and Technical Writer, and Center Administrative Assistant to the Project Teams.

Evaluation and Assessment

The North Dakota State University (NDSU) Worldwide Web Instructional Committee (WWWIC) has been engaged in a range of evaluation and assessment activities. For the purposes of this document, we define evaluation as those activities related to 1) gathering data on systems (usability measures and user feedback), and 2) gathering data on projects (project progress and milestones). Assessment, on the other hand, we refer to as measures of student learning either through our research efforts in scenario-based assessment or more conventional methods.

Assessment of student learning is a key research activity of the Center and is discussed elsewhere. Evaluation breaks down as follows.

Evaluation of Systems

Evaluation of systems takes two primary forms: survey instruments and in-person interviews.

Survey Instruments

Every WWWIC experiment is conducted using the same protocol which was established years ago. Students register themselves using an online system of our invention (Opgrande et al. 2002). This registration creates an account on the appropriate immersive virtual environment and sends a user name and password to the student via email. The student is then presented with a check list of activities to complete. This list always includes a computer literacy survey and a scenario-based assessment form. Following this, the student is directed to their assigned treatment activity (which might be an immersive virtual environment experience or an alternative exercise). Following their “treatment” the students are all directed by their checklist to complete follow-up activities. These invariably include a post-treatment scenario-based assessment, and a usability and feedback survey. Over the years these usability and feedback surveys have been a constant source of information leading to design and implementation revisions. We have years of these data saved.

In-person Interviews

A more recent development is our initiative to record student feedback as they are in the middle of their assignment. We have developed an interview protocol and have implemented a plan where selected students are queried as they use the systems. This is a growing effort and one we propose to continue through the life of the project. These data provide a different insight into both student learning and system usability which informs the progress of system development. We have purchased a digital video camera to record transcripts of these sessions.
Evaluation of Projects

Project evaluation is primarily handled on-site through weekly meetings that set agenda, plan milestones, and check progress. The galvanizing influence on projects is the regular schedule of experiments that are mounted every Fall semester. The team from top to bottom knows that Spring and Summer work is aimed towards making things ready for the Fall. This has become a cultural icon in the group and serves to make things happen on a regular annual basis. This is when we conduct our experiments, which amount to rolling out new versions of systems that culminate a year of research and development.

In addition to this culture driven evaluation, we propose to continue formal external evaluation using nationally respected consultants. In the past we have employed Dr. Lawrenz at the University of Minnesota and Dr. Tomanek at the University of Arizona. These, and others at this level will continue as external check points on progress.

Facilities, Equipment, and Other Resources

To paraphrase Wired Magazine, North Dakota State University is “obscenely well-equipped”. The inventory of equipment and facilities is detailed elsewhere. However, the key point is that North Dakota, as a large and sparsely populated state, has a long history of early adoption of technology solutions. The entire state is wired with interactive video, for example, and has been since the 1960s. North Dakota is home to one of the nation’s first laptop universities, Valley City State University, and there is a high speed internet connection in every single dorm room on the NDSU campus. NDSU has the largest LAN installation in the state, consisting of over 6500 data ports in 35 buildings. The core network is located in the Industrial Agriculture and Computer Center building (IACC). All campus building-networks are served via 100MB, full-duplex, fiber-optic connections from the IACC core network.

In fact, the college tavern across the street from campus is even wired for laptop access. This might surprise the average reviewer, which is why we point it out. North Dakota is the least visited tourist destination in the United States, but it has one of the best educated populations according to national testing, and has the highest rate of high schoolers going to college of any state in the union. Fargo is a bustling center of medical and computer technology with three colleges and a tech school in the immediate area. Microsoft has a major installation here. Besides which Fargo is regularly rated as one of the top places to work and live in the United States. It’s all happening here, so don’t think of us as some kind of Arctic outpost – seriously.

Administrative Support

The main point of contact for administrative activities connected to the North Dakota State University (NDSU) Worldwide Web Instructional Committee (WWWIC), is currently the NDSU Center for Science and Mathematics Education (CSME).

The CSME is prepared to administer the financial and dissemination needs of this project by, in particular, accepting licensing orders as they are placed, arranging for storage and delivery of materials as they are ordered, and operating as a continuous point of contact capable of facilitating communication between customers and project participants in the event of system problems. CSME will serve as a clearinghouse for materials and as a source of continuity as markets and project membership changes over time.

Sustainability

The North Dakota State University (NDSU) Worldwide Web Instructional Committee (WWWIC) has created a “spin-off” company, WoWiWe Instruction Co. (Taxpayer Identification Number 456002439), that is actively competing for Small Business Innovation in Research (SBIR) funding from federal agencies. As of this writing two proposals are currently under review.

SBIR/STTR Phase I: Geology Explorer uses in Earth Science

A seven month project aimed at studying the feasibility of using modified versions of the Geology Explorer software to improve K-12 science education by a) freely disseminating our software to a range of public and private schools in North Dakota; b) creating and providing an array of support documentation to accompany the software: user manual, teacher guide, suggested lesson plans; c) providing online "help desk" technical support for the period of the grant; d) coordinating assessment studies and lesson narratives conducted on our behalf by teachers at the schools.
SBIR/STTR Phase I: Scenario-based Assessment in the Public Schools

A seven month project aimed at studying the feasibility of using innovative scenario-based software for student assessment to improve K-12 science education by: a) freely disseminating our software to a range of public and private schools in North Dakota; b) creating and providing an array of support documentation to accompany the software: user manual, teacher guide, grading templates; c) providing online "help desk" technical support for the period of the grant; d) providing tools to develop new assessments; e) coordinating assessment studies conducted on our behalf by teachers at the schools.

Sustainability Strategy

The SBIR program is presented in phases. Phase I is for "feasibility studies" that determine whether a potential product might succeed in the market. We have a number of potential products arising from the research efforts of the group, and plan to continually submit these to SBIR. Those that succeed are eligible for Phase II funding, for "proof of concept" development. These are larger 2-3 year projects aimed at producing a viable prototype. We envision a number of these proposals submitted in the next few years. Phase III development is undertaken solely by the company without external support.

The WWWIC strategy is to develop products based on research efforts, and to employ graduates of our program as developers. The two proposals currently under review were submitted by John Opgrande who recently graduated from NDSU with a Masters degree in Computer Science. Mr. Opgrande’s thesis, “Web-Based Education Research Management (WERM)” completed in May, 2003, was about his work developing the online systems for WWWIC pilot studies (Opgrande et al. 2002). As outstanding students complete their studies, we work towards keeping their expertise in the group by creating business opportunities that follow from their research studies. In this way, we propose to create a pipeline of talent that flows from research into product development and long-term dissemination.

What’s New Here?

Computer games are an enormous industry currently grossing more per year than the motion picture industry. However, the development of educational games has been largely disappointing. We propose to fix that.

At the intersection of anthropology and computer sciences is growing a new multidisciplinary frontier of study on learning through virtual environments. Spreading out from this intersection are studies involving the best that the social sciences and humanities have to offer a science of learning in virtual worlds. The idea of enculturation has been grasped at by other disciplines seeking to explain how contexts impose limits and designs on learning (e.g., Hagge 1995, SM Smith 2001, Tishman and Perkins 1993, Bishop 1988, Haydu 1974). At the level of horizontal theory (Dupre 1994), the disciplines are uniting to produce synergetic approaches to the science of learning in virtual educational worlds. For example, we propose to organize and lead this new subfield to new and more sophisticated levels of organized experimental scientific thinking and practical application that will benefit the sciences, the humanities, and society.

Research in immersive virtual environments for education is scattered across a range of journals and conferences with no clear set of organizing principles or standards. The Center will host a new e-journal that will consolidate the discipline.

Is it possible that our immersive approach provides an alternative modality that is more naturally tailored to certain cultural groups? This warrants study.

All the systems proposed here are based on the idea of establishing a role for the player to assimilate in a problem-solving context. This is the enculturation idea taken to the next level. What you get when you play a WWWIC game is a discipline specific problem solving context where, if you are to succeed, you learn how to think and act within the context. This is an old idea: cognitive apprenticeship, re-made in a new virtual immersive form. It’s fairly clear from the literature that we are the main group taking this particular approach.