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ABSTRACT

The earth sciences is an evolving set of disciplines encompassing more than 30 specialties; however, earth scientists continue to be trained within the traditional disciplinary structure. Earth science education should focus not only on student acquisition and retention of factual knowledge, but also on the development of higher-order skills needed to operate in a technical world. These include the capacity for complex problem solving, lifelong learning, and effective interpersonal interaction. One of the most promising pedagogies to meet these goals is the effective integration of World-Wide-Web-aided instruction. Several characteristics of the Web which highlight its potential as an instructional tool include: (1) its asynchronomous nature; (2) its ability to include simulation of complex earth systems; (3) the ability to provide student access to real time earth systems data; and (4) the ability to deliver authentic assessment. Students enrolled in Physical Geology (n=545), a core curriculum class at Texas A&M University, were administered questionnaires at the beginning and end of the fall semester to ascertain: characteristics of the study body taking this course and effectiveness of the associated class Web sites in terms of their ability to foster student learning. The study found that 56% of students enrolled in this course were business majors; 68% enrolled in it because they perceived it to be the easiest science class that fulfills the university requirement; 79% reported that they viewed science as having little or fair impact on their lives; and 74% believed that the development of strong quantitative skills is fairly or very important for their education. Students perceived that they had little to fair knowledge about computers. Instructional Web sites either need to be fairly simple or contain tutorials on the use of the Web site. (Contains 52 references and two tables.) (PVD)

Effective Integration of the World-Wide Web in Earth Science Education

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Effective Integration of the World-Wide Web in Earth Science Education

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> *Earth science education not only needs to focus on student acquisition and retention of factual knowledge, but also on the development of higher-order skills needed to operate in a technical world. These skills include the capacity for critical thinking and complex problem solving, lifelong learning, and effective interpersonal interaction and teamwork. One of the most promising pedogogies to meet these goals is the effective integration of WWW-aided instruction in earth science education.*

The Earth sciences is an evolving set of disciplines encompassing more than thirty specialties, each with its own arcane language and culture. While Earth scientists have a greater appreciation of the connectedness between different Earth systems such as the ocean, atmosphere, and terrestrial systems, they continue to be trained within the traditional disciplinary structure. Earth scientists are now being asked to solve complex, multidisciplinary problems in areas that often cut across disciplinary boundaries such as global climate change, resource exploitation, hazard mitigation, waste management, geotechnical engineering, groundwater development and environmental monitoring. As a result of the interdisciplinary nature of these issues, multidisciplinary Earth-science teams have become the operating norm in many Earth science industries [Posnick, 1989; Satter and Shaw, 1997]. Therefore, there is a gap between the academic structure that trains most Earth scientists and the characteristics of the systems and problems that these scientists study.

The lay public must also contend with complex issues surrounding the interrelationships of Earth systems and human society. The key to the development and implementation of acceptable and effective solutions to Earth-systems related problems lies in the development of an active and knowledgeable lay public, thus educators at both the secondary and university level must effectively educate students in these issues. Student education at all levels, of course, is not solely restricted to the acquisition of factual knowledge but also the development of a basic set of higher-order skills needed to operate in an increasingly technical world. These skills include the capacity for critical thinking and complex problem solving, lifelong learning, and effective interpersonal interaction and teamwork [Div. Research, Eval. & Comm., 1996].

In order to accomplish these educational goals, particular attention needs to be placed on the education of future Earth science instructors that will teach at the secondary and University level. These instructors need to appreciate the interdisciplinary nature of Earth systems and the complex nature of interactions between the Earth and human society. In addition, they must be able to transfer their knowledge and skills using new teaching methodologies that stress the development of higher order skills in students [Mayer, 1990; NSF, 1990, 1993; Carpenter, 1996].

In response to the issues discussed above, there has been some reform of instructional pedagogy at undergraduate educational institutes teaching Earth science. Many institutions have responded by revamping introductory Earth-science courses to focus on Earth systems [Schneider, 1988; Mayer, 1991a,b, 1995; Suiter, 1991; Fortner et al., 1992]. There has also been an introduction of upper division Earth science classes that address these issues, even though they are generally more focused that introductory classes. These courses are explicitly designed to highlight the interdisciplinary nature of the applied geosciences and address the relevance, and difficulties in using the information supplied by the geosciences in making decisions of economic, environmental, and societal consequence. Outside of these changes though, teaching pedagogy that stresses the development of higher order skills in students has made little inroads in Earth science classes for majors and nonmajors. Hence, Earth-science educators still tend to produce graduates with strong technical backgrounds in narrow specialties and relatively weak skills in critical thinking and complex problem solving, writing, and effective interpersonal interaction and teamwork.

The World-wide Web (WWW) has been incorporated into most sections of Physical Geology (GEOL 101), a large, introductory class in Earth science at Texas A&M. The WWW has the potential to support pedagogical changes in GEOL 101 which promote appreciation of Earth science as well as the development of higher-order skills in students. This paper reports early assessment of the impact of the introduction of the WWW in this class, as well as an evaluation of the characteristics of the students enrolled in the class. This assessment will be used to drive future development of the class Web sites.

Instructional Technology and Educational Reform

Reform of instructional pedagogy at American educational institutions during the last twenty years has focused on enhancing the higher-order skills of students and meeting the educational needs of underrepresented groups [Means, 1993]. The objectives of the reforms include the development of pedagogy that helps students evolve from passive learners to active learners, and develop the ability to think and write critically, solve complex problems, and work together in teams [Pinet, 1989; Carpenter, 1996; Means, 1993].

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The primary theoretical basis for most strategies of curriculum and instruction reform are the tenets of constructivitism, which states that acquisition of higher-order skills of comprehension, reasoning, and subject knowledge is dependent on a student's interaction with content and not through passive transfer of facts and content [Collins et al., 1989; Resnick, 1987; Cheeks, 1992; Saunders, 1992]. A wide range of instructional reform have been suggested, including reducing the importance of lecturing; incorporating more active, hands-on demonstrations and laboratories; and increasing the use of collaborative learning, simulations, open-ended questions and problems, and writing assignments to explore topics [Pinet, 1989; MacDonald et al., 1992; Pavelich and Moore, 1996; Felder, 1996; Niemitz and Potter, 1991; Wright, 1996; Richards et al. 1995; Carpenter, 1996]. The reforms are thought to enhance learning among students of varying learning styles including "second-tier students" and underrepresented groups such as minorities and women [Stice, 1987; Harb et al., 1993; Lin et al., 1996; Tonso, 1996].

In addition, educational reform has also explored different forms of student assessment. The reforms typically focus on decreasing the emphasis on traditional assessment methodologies which tests content knowledge (e.g., algorithmic manipulations, closed-ended questions, and multiple-choice exams) and increasing the use of authentic assessments to test problem solving, critical thinking, and writing [Baker, 1993; Nuhfer, 1996; Niemitz, 1996; Shaeiwitz, 1996]. The new assessment methodologies that have been used in university science and engineering classes include evaluation of student responses to open ended questions and problem formulations, writing assignments, capstone and research projects, and student portfolios [Pavelich and Moore, 1996; Richards et al., 1995; Wright, 1996; Felder, 1996; MacDonald et al., 1992; Badger, 1995; Carpenter, 1996].

Instructional technology, including television, videodisks, computers, and the Internet, has been used to support educational reform for the last 50 years through its ability to create situations where students participate in authentic, complex tasks and support classroom organizational changes [Means, 1993; Anglin, 1995]. Means [1993] reviewed the use of instructional technologies to support educational reform and classified the different used of instructional technology in four different classes: tutorial, exploratory, application, and communication (Table 1).

Unfortunately, the effectiveness of instructional technology in supporting educational reform is mixed [David, 1994]. Successful introductions of technology into educational settings has three general characteristics: (i) technology introduction is based on the tenet that the technology can promote active learning by students, which results in enhanced student understanding and problem-solving skills, (ii) the introduction incorporates support for instructor development, and (iii) the introduction involves a relatively small number of schools or classrooms [David, 1994].

Table 1. - Classification of education technologies (taken from [Means, 1993])

Category	**Definition**	**Examples**
Tutorial	Information, demos, or simulations in a sequence determined by the system. Tutorial systems may provide for expository learning (the system displays a phenomenon or procedure) and practice (the system requires the student to answer or questions or solve problems).	• Computer-assisted instruction (CAI) • Instructional television • Some videodisc/ multimedia systems
Exploratory	Information, laboratories demonstrations, or simulations that are under student control. Some systems provide the context for discovery (or guided discovery) of facts, concepts, or procedures.	• Microcomputer-based laboratories • Microworlds/ simulations • Some videodisc/ multimedia systems
Applications	General-purpose tools for tasks including composition, data analysis, and data visualization.	• Word processing, database and spreadsheets software • Statistical/mathematical modeling and graphing

		• Visualization and GIS software
Commun-ications	Communication Systems that allow groups of teachers and students to send information and data to each other through networks or other technologies.	• Local area networks • Wide area networks • Interactive distance learning

The World Wide Web as Instructional Technology in Earth Science Education

Research and development of World Wide Web-based instructional materials for Earth science education, as in most other disciplines, has recently emerged as the single most exciting application of instructional technology [Bernie, 1995; Caudron, 1996; Graves, 1996; Neilson and Thomas, 1996]. Many science and engineering disciplines have begun to distribute course materials over the World Wide Web (e.g., engineering [Schwarwalder, 1996], chemistry [Holmes and Warden, 1996], physics [Smith and Taylor, 1995], geology and geophysics [Boyd and Romig, 1997], and K-12 [Reed, 1995]). The same is true of the Earth sciences where the amount of learning material being published on the web has grown explosively. In November of 1996, 375 earth science course resources were being distributed by faculty in nearly 100 universities and colleges (http://www.uh.edu/~jbutler/anon/anonfieldtrips.html). This was up from 75 resources offered by 40 universities in November 1995.

There are several characteristics of the WWW which highlight its potential as a instructional tool for Earth science education including (i) its asynchronous nature, (ii) its robustness in terms of the ability to include simulation of complex Earth systems, (iii) in that the WWW can provide student access to real-time Earth systems data, (iv) and because the WWW can deliver "learner-input centered" or authentic assessment. Interaction with material on the Web is asynchronous due to the hypermedia structure of the WWW. This characteristic allows students to interact with educational materials in a way that best matches their learning style. The nature of software (e.g., JAVA, Visual Basic) available for the Web also allows this medium to be used to explore complex problems through simulation and modeling. This can promote active participation by students as they explore complex Earth phenomena. The Internet and the WWW is uniquely suitable to promote student access to real-time data on Earth processes such as earthquakes, volcanic eruptions, and floods. In fact, the wide proliferation of Earth science data available online from federal agencies including NASA, USGS, NOAA, and the EPA, make the use of the Internet and the WWW in the Earth science classroom particularly promising. The platform independence of educational material distributed over the Web also greatly reduces development time and effort compared to other dissemination methods such as CD-ROM. Finally, because the Internet seems to be increasing in importance in everyday life, the use of the WWW in the classroom promotes the education of technologically-savvy students (e.g., empower student learning).

A radical departure from traditional instruction requires new approaches to evaluation. Traditional assessment grades on a few hours of formal testing without understanding the students' intellectual struggle or any documentation of progress. Grades are assigned based on recall and recognition of facts. In order to determine the depth of student understanding a more learner-centered plan is warranted. A growing movement towards "authentic assessment" is emerging in the field of science education. Authentic assessment has many facets requiring that students demonstrate what they can do by performing tasks that are complex and require production of solutions or products [Darling-Hammond et al., 1996]. These approaches include essay examinations, oral exhibitions and performances in areas such as debating and the arts. They also include individual and group projects requiring analysis, investigation, experimentation, cooperation, and written, oral, or graphic presentations of findings. These approaches, broadly classified as "learner-input centered" or "student-observational centered", can be implemented through the WWW [Regan and Sheppard, 1996].

Assessment of WWW-based Instruction in the Earth Sciences.

Adapting curriculum and instruction to stress active student participation, cooperative behavior, and exposure to open-ended, authentic problems is generally effective in increasing student interest in science and engineering, as well as developing higher-order skills in critical thinking and problem science and engineering, as well as developing higher-order skills in critical thinking and problem solving. Pinet [1989] presented anecdotal evidence that active student participation in the development of conceptual models of geologic phenomena led to increase student interest in the Earth sciences and helped develop a "deeper understanding of the intellectual conduct of science". Carpenter [1996] quantified significant increases in content knowledge and commitment to teaching environmental issues of in-service teachers after their participation in an environmental Earth science class which employed a constructivist epistemology and active learning. Researchers at the Colorado School of Mines utilize senior-year capstone classes which provide a series of open-ended questions in engineering to help develop complex thinking and problem solving skills in undergraduates [Olds et al., 1990; Miller and Olds, 1994]. Pavelich and Moore [1996] evaluated the curriculum in terms of its stated goals of enhancing the development of higher-order skills in the undergraduates using hour-long, structured interviews. The authors showed that there was significant development of higher-order skills of the students during their undergraduate education, though the authors felt that the level of student development fell below the levels needed for a professional engineer. Pavelich and Moore [1996] concluded that to enhance student development even further would require adoption of the instructional methodologies used in the capstone classes throughout the curriculum. Instructional models based on active-inductive-cooperative learning in chemistry and chemical engineering have also been shown to be effective in enhancing student performance and interest in these subjects, increasing problem solving skills of students, and building teamwork among students [Wright, 1996; Felder, 1996].

It is reasonable to expect that the adaptation of the types of instructional reforms advocated in the reports above to Web-based delivery will likewise yield important gains in the development of higher-order skills in students, especially when developing their understanding of interdisciplinary issues in Earth science. There is a need to further explore, develop, and assess effective teaching mechanisms designed to strengthen interdisciplinary understanding and the development of higher order skills of target populations [Hannah, 1996], while at the same time not ignoring those end users who have limited available technology or expertise [Huff and Butler, 1996]. Fairly limited research is being conducted to assess the impact of Web-based instruction on learning outcomes. A recent survey of the ERIC educational database uncovered no articles published within the past five years that have assessed web-based learning models.

WWW-based Instruction in the Earth Sciences at Texas A&M University

Physical Geology (Geology 101) is a first-tier core curriculum science course offered in the College of Geosciences and Maritime Studies. Approximately 2500 students enroll in the course per year to fulfill four hours of their science requirement. For many of these students, this course is their first and last introduction to science at the university level. Web-based instruction has been introduced into most classes of GEOL 101. The class web sites are basically similar in that they provide communication with the instructor through email; class organizational information including syllabi, test grades, and exam schedules; class notes including graphics; several virtual field trips of Texas geology; and links to outside WWW sites of Earth science information and simulations. These features are fairly typical of most Web sites connected with specific classes.

Table 2. - Physical Geology (GEOL 101) Web sites at Texas A&M University

Class Web Sites	Universal Resource Locators (URLs)
GEOL 101	http://geoweb.tamu.edu/courses/geol101/chesterf/ http://geoweb.tamu.edu/courses/geol101/chesterj/ http://geoweb.tamu.edu/courses/geol101/grossman/ http://geoweb.tamu.edu/courses/geol101/herbert/geol101/

Objectives and Methods This study will focus on the evaluation of WWW-based instructional materials used in several Physical Geology classes at Texas A&M University. Specifically, the objectives of this study are to (i) characterize the student body enrolled in GEOL 101 at Texas A&M in terms of their demographics, expectations for the course, and initial expertise using computers and the Internet, and (ii) assess the effectiveness of the associated class Web sites in terms of their ability to foster student learning. Students were administered questionnaires at the beginning and end of the Fall semester of 1997. The questionnaires included specific questions on demographics and more general questions where students could record statements concerning their perceptions of the usefulness and frustrations connected with the class Web sites.

Results The students enrolled in Physical Geology, a core curriculum class at Texas A&M, are dominantly female and first-year students (Fig. 1). Nearly 50% of the student are from suburban high schools and 63% of the students own their own computers (Fig. 1).
Of the 545 students responding to the questionnaire at the start of the semester, the preponderance (56%) of students enrolled in Geology 101 are business majors (Fig. 2). These students are generally not very science orientated. Most students (68%) reported that they enrolled in Geology 101 because they perceived it to be the easiest science class that fulfills the university requirement or that the class was recommended to them for this reason. Students (79%) also reported that they viewed science as having little or fair impact on their lives (Fig. 2). . This makes the generation of enthusiasm for the subject problematic for the instructor. Bucking this trend, the students generally (74%) believed that the development of strong quantitative skills is fairly or very important for their education and careers (Fig. 2).

While most 101 students owned their own computers, and all 101 students have access to personal computers through the University, they perceived that they had little to fair knowledge about computers (Fig. 3). Their perceptions concerning their expertise in using the Internet was even lower (Fig. 3). This indicates that instructional Web sites either need to be fairly simple or contain tutorials on the use of the Web site.

Conclusions

In general, the students enrolled in Physical Geology at Texas A&M have the resources to utilize the WWW in their classes but probably lack the knowledge to gain full benefit of the instructional materials developed through the WWW without additional training. This training could be conducted as self-paced tutorials distributed through the Internet or as labs connected with the class. In order for students such as these to fully utilize the Web for instruction, developers of instructional Web sites will have to pay particular attention to development of clear, understandable sites with easy and consistent navigation and the limited need for more advance technological knowledge by the endusers. These criteria can pose severe difficulty for the average faculty member who wishes to develop advanced instructional Web sites.

Given the call to increase Internet access in American schools [Clinton, 1997], the potential of the Internet and the World-wide Web to support the development of higher-order skills among Earth science students and preservice teachers, and the need for the assessment of the use of the curriculum materials distributed over the Internet, there is a need to for the coordinated development and dissemination of authentic and effective Web-based Earth science curriculum materials by the Earth science community. The overall goal of The GEODE Project (Geoscience Education in an Online Development Environment), a collaborative effort of geoscience and education researchers at the American Geological Institute, Texas A&M University, Colorado School of Mines, and University of Texas-El Paso, is to create a virtual center for Earth science education aimed at providing Web-based curriculum material and expertise to Earth science educators. The structure of the virtual center and the Web-based curriculum materials will be one which fosters active learning, the development of problem-solving skills and critical thinking, and the support of diverse learning styles. Finally, the activity of the virtual center will revolve around the assessment of The GEODE Project using authentic, "learner-input centered" techniques. The structure of the GEODE project is shown in Fig. 4.

Materials developed will be modular in nature, incorporate extensive use of computer simulations and a game-playing pedagogy designed to enhance conceptual understanding, and follow an established template designed to make incorporation of new modules into the project as simple as possible. Community input on the module template will be solicited and the template established, prototype modules will be developed and implemented by each home institution, and assessment done on the results.

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