

The Large General Education Science Class: Implications for Distance Learning

By
William A. Prothero, Jr.
Dept. of Geological Sciences
University of California Santa Barbara

Submitted to:
Computers and Geosciences
Elsevier

Keywords: education, network learning, oceanography

Abstract

The internet and worldwide web provide powerful new education and information delivery capabilities which can be used to achieve educational goals. However, it is important to review overall trends in science teaching practice and attempt to identify areas where network learning is likely to make strong contributions and where it may be weak. Educators agree that science knowledge is most effectively acquired when students apply a range of cognitive processes during the learning process. Trends in science education are directed toward an emphasis in active learning and group learning, increased reliance on writing, increased use of computers to provide students with access to large datasets for open-ended problems, and depth of treatment is emphasized over coverage of many subjects.

Experience in large introductory classes can be applied to the design of effective network based classes. The UCSB Oceanography Class is typical with 200-300 students per quarter, 3 hours of lecture, and 2 hrs of lab per week. The focus of the class is on learning about science by doing science. For example, students must pose a problem related to plate tectonics to investigate, use the "Our Dynamic Planet" CD-ROM to acquire data from its datasets, and write a scientific paper based on their investigation. Network technology is used extensively for homework entry and automatic grading, and student access to their grades for individual activities.

A class is framed in terms of content, presence, and social context. Except for presence, network approaches could provide substantial improvements. Technology developments in peer review software and simple (technically) posting of student work to the network, combined with bulletin board, chat and listserves, could support the development of a social context. Experience suggests that the success of network approaches will depend strongly on individual student capabilities, needs and goals.

1. Introduction

The internet and worldwide web provide powerful new education and information delivery capabilities which can be used to achieve educational goals. The internet will play an important role in future educational systems, whether as an add-on to existing classroom based

instructional methods, or in a distance learning mode where there is very little “face to face” contact. In many colleges and universities a transition has already been made, at least in spirit, to “distance learning” in the form of introductory courses consisting mostly of lectures, delivered to very large numbers of students, and a few machine graded exams. In this environment of rapidly increasing internet course offerings, it is important to review overall trends in science teaching practice and attempt to identify areas where network learning is likely to make strong contributions and where it may be weak. This paper will review some of these trends, provide an example from the author’s own work, and make some suggestions about future developments in educational uses of the internet.

Our knowledge of good teaching practice suggests that large lecture based classes have reduced educational value over smaller classes where per-student resource limitations are not so severe. This is unfortunate because introductory science classes are the only science classes that most of our students will take at the college level, and ultimately they will have a strong impact on the science literacy of our population. These students will take their place with the majority of non-science specialist voters who will determine public support for science. Many will become elementary and secondary teachers who will teach the new generation of students. They will also be called upon to make informed votes when science results have controversial public policy implications. Competition for dwindling resources by an increasing world population makes it inevitable that science results will be slanted to support the views of stakeholders who will benefit from a particular policy. People will need to be able to discriminate credible science from fallacious science and legitimate disagreement from a distortion of science results. Our population will need to be critical thinkers about science.

Large introductory science classes provide an interesting perspective in relation to distance learning classes. Not only do they have similarities in lack of personal contact between professor and student, but they are encouraged by many college and university administrations. Distance learning classes also have economic value to the institution. Just as the student numbers for individual introductory classes has crept up, there will be institutional pressure to allow the numbers to increase in distance learning classes, and once in place, to be taught by less experienced teachers at lower cost. In view of this, it is vital to define what constitutes a “good” learning experience. There is enormous opportunity to improve the quality and availability of the

science learning experience by using the internet effectively. Nevertheless, I appreciate the possibility that efforts for increased efficiency may subvert legitimate educational ideals.

Because of the rapid development of internet based classes, it is useful to shift our focus temporarily and review some of the trends in classroom based science education. These trends can then guide us in determining the best practices for network courses, and lead us in compensating where online strategies are weak.

2. The Need for Reform

The processes of acquiring knowledge and understanding are complex and subject to much debate among science educators and science education researchers. There is disagreement about what it is, how it occurs, and how to measure it. In spite of this debate, the science education community is united in calling for the reform of science education. The strongest disagreement is over the nature of this reform (Linn, 1992, 1987; Gardner et al., 1990; Shymansky & Kyle, 1992). Most of the educational research in science learning has been done in K-12 settings. The research results are especially applicable to lower division general education science classes where a diversity of background, capabilities, interests, and ethnicity challenge the most common teaching pedagogies in our universities and colleges.

It is generally agreed that science knowledge is most effectively acquired when students apply a range of cognitive processes during the learning process (National Research Council, 1996; American Geophysical Union, 1997; Meyers and Jones, 1993) . These processes include not only the memorization of facts, but the use and integration of scientific principles to solve unfamiliar problems. Activities such as passively listening to a lecture, or answering simple questions from a textbook are examples of activities often requiring only low level cognitive processes, while applying knowledge from diverse subject areas to solve an unfamiliar problem, testing theories using evidence, and writing are activities generally requiring higher level cognitive processes.

It is interesting to compare the activities of practicing scientists to how science is presented in the large introductory science class. Some of these ideas can be illustrated with a short discussion of figure 1 (modified and expanded from Duschl, 1990). The figure is a diagram representing the major features of the process of knowledge creation, testing and acceptance that we call science. Of prime importance is background knowledge (BK), which constitutes both

facts and the theories that explain them. Background knowledge is not all equal. It may be core

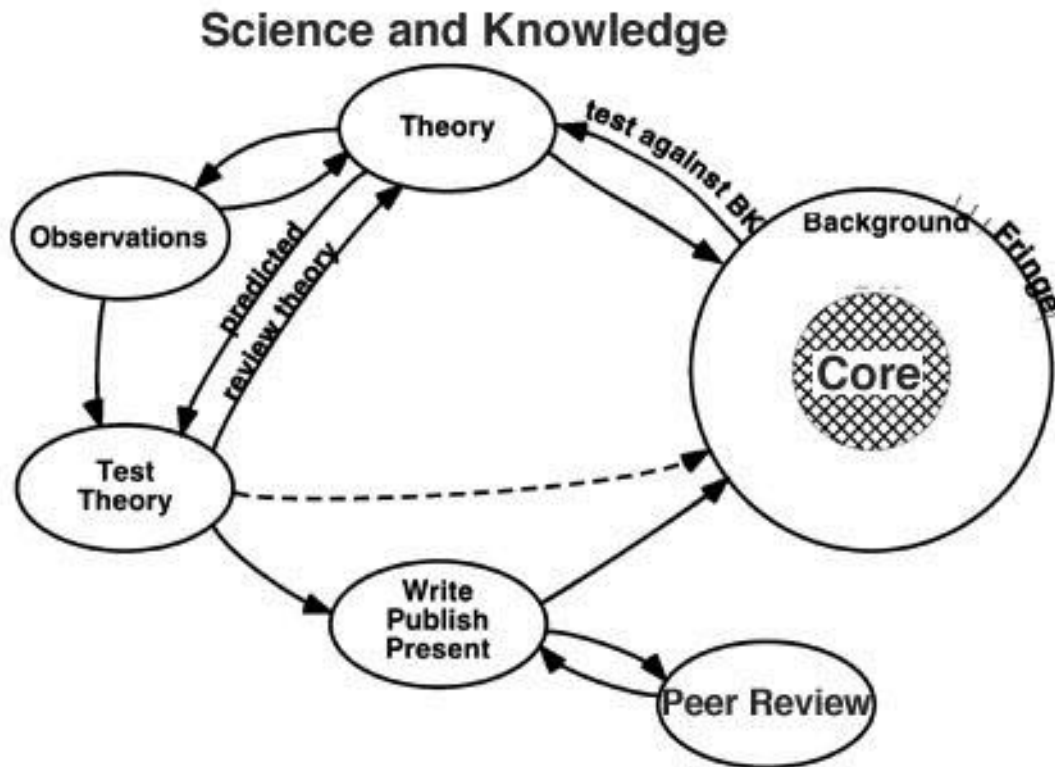


Figure 1. Diagram of the process of knowledge acquisition and acceptance in science.

knowledge, which is widely accepted (e.g. the theory of plate tectonics) or it may be “fringe” knowledge, which is controversial (e.g. creation theory) or accepted by few (e.g. new developments in a field). It is the goal of the researcher to test this body of background knowledge (or new knowledge) with the intent of clarifying its status in the hierarchy of knowledge acceptance. In this process, a theory (or explanation) is created or selected for testing. This theory is first tested against existing background knowledge. New observations may be made and are then compared to the predictions of the theory. If the test is passed, communication with peers, publication and peer review move the knowledge closer to the core. Further activities continue to test, refine, reject, or accept new theories and facts that comprise the pool of background knowledge as it sinks toward the inner core of wide acceptance. Occasionally even core knowledge is challenged and rejected. This was the case when the accepted view of the earth at the center of the solar system was challenged by the theory that the sun was at its center. This view of science exposes theories as subject to constant testing and refinement. It also

shows that some theories are better than others and that the rejection of fringe scientific theories is common in science, while core theories are unlikely to be rejected.

How does this view of the process of science compare to what the student experiences when we actually teach science? Most of college science education relies heavily on the lecture, and is taught in its final form as facts to be remembered for exams. However, research on the effectiveness of the lecture shows that (from Meyers and Jones, 1993):

- Students are not paying attention to what is being said in a lecture 40% of the time (Pollio, 1984, p11)
- In the first 10 minutes of a lecture, students retain 70% of the information, while during the last 10 minutes, students retain 20% (McKeachie, 1986, p.72).
- Students lose their initial interest. Attention levels continue to drop during the lecture (Verner and Dickinson, 1967, pp.90-91)

The above statements can easily be verified qualitatively by the instructor who asks his/her students, at the end of his/her lecture, to write (and hand in) a few sentences about the main points contained in the lecture. An appreciation of the dynamic view of knowledge as changing, being challenged, and constantly renewed and refined (Duschl, 1990, p7) is absent in most general education science courses. Our lower division students especially, are most often presented with textbook explanations that they must learn (i.e. memorize) to repeat during exams. This suggests an obvious question: “How can a population that does not understand that scientific knowledge is constructed through a dynamic process of testing and refinement be expected to give credibility to the results of scientific research and to support sound national science policy through their participation in the democratic process?”

3. Trends in Science Teaching

A number of trends seem to be emerging in science teaching (National Research Council, 1996; American Geophysical Union, 1997). These are briefly summarized in the following list:

- Active learning and group learning (Meyers and Jones, 1993). Students work in groups, taking advantage of a diversity of backgrounds to help them learn from each other. In addition, students are asked to articulate their positions and consider those of others .
- Increased reliance on writing.

- Increased use of computers to provide students with earth datasets for open-ended problems (Prothero, 1995), experiment simulations (Lewis and others, 1993), “virtual field trips” when real field trips are not practical (or as adjuncts to real field trips), communication through email, World-Wide-Web access, and to ease administrative tasks and free up teacher time to interact with students.
- Depth of treatment is emphasized over coverage of many subjects.

One of the most visible trends is toward collaboration in the classroom, and a “constructivist” pedagogy. Constructivism is based on the premise that students construct meaning based on experiences and social interactions. Therefore, the constructivist classroom centers around activities where students discover the principles that would normally be simply told to them by the teacher. Table 1 (modified from Brooks and Brooks, 1993) contrasts the conventional classroom with the constructivist/collaborative classroom. It is clear that there is a major difference.

Conventional Classroom	Constructivist/Collaborative Classroom
Teacher presents material by lecturing.	Teacher sets “big picture” problems, then asks students to collaborate to find answers.
Fixed amount of material is covered. Students are tested on answers to specific questions.	Pursuit of student questions is valued. Students are encouraged to “synthesize” through writing and class presentations.
Activities focus heavily on directive or “canned” exercises.	Activities are focused on primary sources of data and its interpretation.
Teacher seeks the “correct” answer.	Teacher seeks the students’ point of view in order to understand students’ present conceptions for use in subsequent lessons.
Assessment of student learning is viewed as separate from teaching and occurs almost entirely through testing.	Assessment of student learning is interwoven with teaching and occurs through teacher observations of students at work and through student exhibitions and portfolios.
Students primarily work alone.	Students primarily work in groups.

Table 1. Contrasts between conventional and constructivist/collaborative classrooms.

4. Learning Science by Doing Science

Recent reports from several national science organizations (AAAS, 1993; AGU, 1997; NRC, 1996) emphasize the importance of engaging students at all levels in the process of science, in addition to the acquisition of science content knowledge. It is emphasized that content knowledge, without an understanding of the context within which science operates, does not adequately address the issue of “science literacy”.

The author’s work in science education is based on the assertion that in this world where change occurs within years, rather than lifetimes, and in which the creation of new scientific knowledge is outpacing our ability to absorb it, our goal should be to teach students about the process of doing science and to generate interest in keeping abreast of new developments in science. The science iterate student should understand the role of scientific theories, that some theories are better than others and that scientific knowledge creation is a process that includes disagreements, false starts, and revision of current knowledge. Active participation in realistic science activities is much more effective in teaching science literacy than simply telling students about science in a lecture. In a well-designed learning environment we don’t need to focus so much on content coverage because content knowledge will be acquired naturally through purposeful activity. This approach also has the advantage broadening students’ view of science from the memorization of science results to a dynamic system of knowledge creation.

These assertions are supported in the education recommendations of several national organizations. *“Introductory courses for all students should offer a serious encounter with both the processes and essential concepts of mathematics, science, engineering, and technology. The courses should be problem-driven, emphasize critical thinking, have hands-on experiences, and be taught in the context of topics that students confront in their own lives”* (National Research Council, 1996). *“Reaffirm the importance of classroom, laboratory, and field activities that encourage active inquiry, and illuminate societal issues and the connections between scientific and nonscientific disciplines. Decrease the emphasis on fact-focussed, lecture-style courses. Emphasize in-depth understanding of a few fundamental elements in the disciplines and the development of critical-thinking skills”* (AGU, 1997).

5. An Implementation Example: UCSB Introductory Oceanography

The University of California, Santa Barbara (UCSB) Oceanography class has 200 - 250

students each quarter. It is a popular choice for non-science majors to fulfill a general science requirement. Philosophically, the course is viewed as both a "terminal" course for non-scientists, and as a "feed-in" course to attract earth science majors. The class covers the formation of the earth and its physical features, waves and beaches, the physical and chemical properties of the ocean, the climate, and world fisheries. The course is taught once per quarter and is taught by one of a pool of approximately five faculty members from the Department of Geological Sciences. There are 3 hrs of lecture and 2 hrs of lab section each week. Lab sections are taught by teaching assistants (TA) who receive varying amounts of supervision from the class instructor.

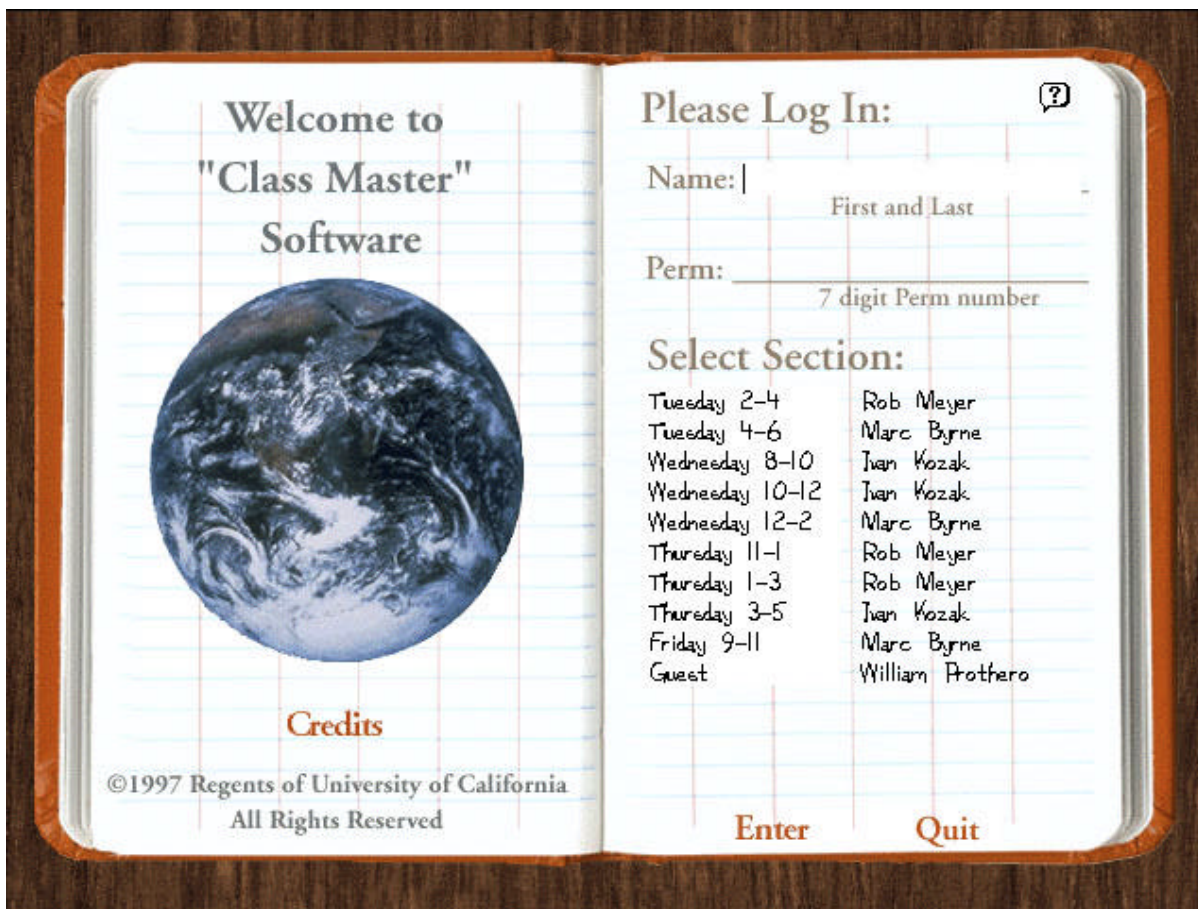


Figure 2. Login screen. Students enter their name, ID number and section. Login and logout times, homework and game scores, and other information are automatically recorded in their activity record.

This class is typical of many large classes taught at public universities. It is strongly lecture focused and grading is on the basis of a small number of machine graded multiple choice

exams. Laboratory and/or section meetings are taught by graduate student teaching assistants, often with little input from the course instructor. In 1995, modifications were made to the oceanography class to support inquiry learning in the lab sections, and a change of focus during lectures toward the lab section activities. The philosophy was to teach students about science by having them actually do science. A computer lab was installed (funded by NSF Instrument and Laboratory Improvement Program and UCSB) and a CD-ROM entitled “Our Dynamic Planet” was created. A scientific inquiry experience using the data on the CD-ROM, complete with a scientific paper writing assignment, was introduced. The lab exercises were revised to depend

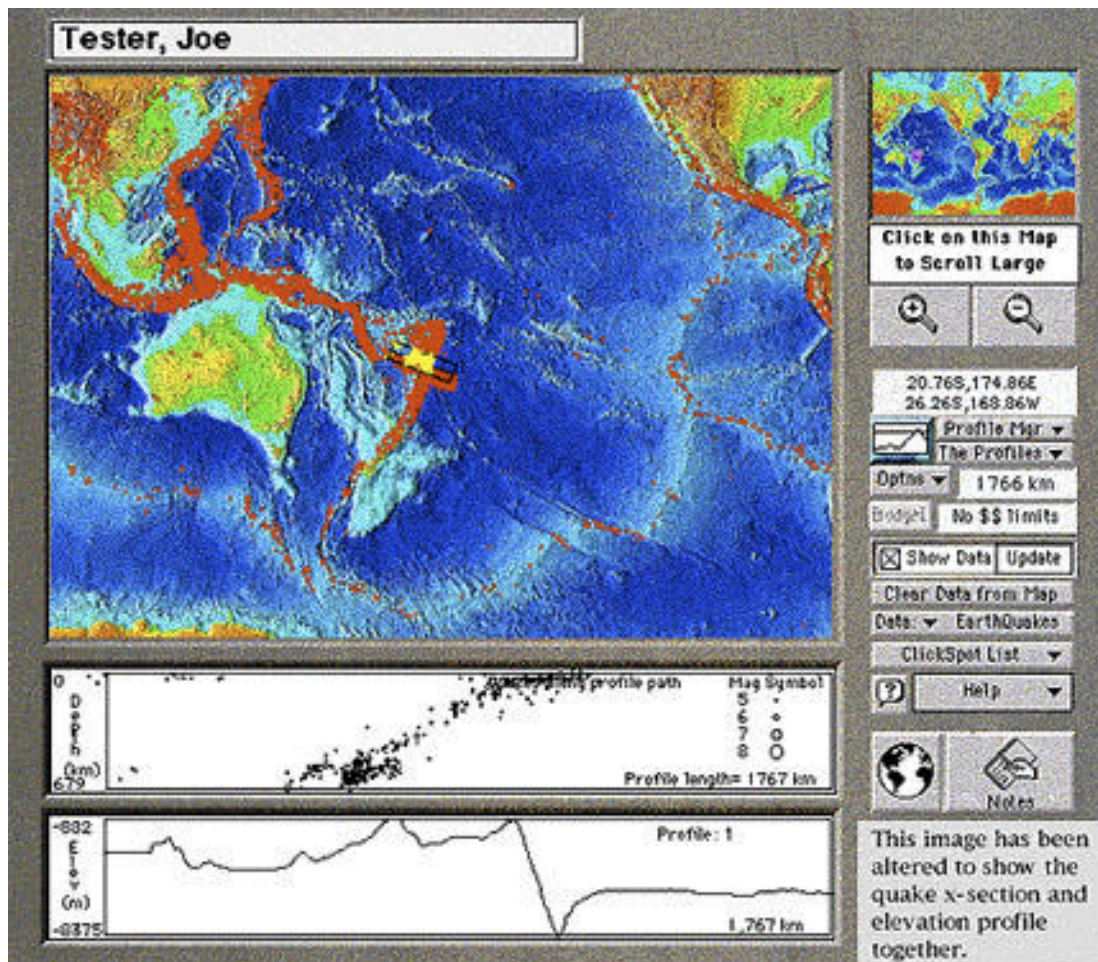


Figure 3. This figure shows one of the data screens. An earthquake cross-section is shown plotted across the Tonga Trench. Students select the cross-section endpoints and can choose the plot scales and vertical exaggeration if desired.

more on small group activities, less on TA lecturing, and supported with a weekly computer graded pre-lab homework assignment. The homework assignment is effective in insuring that

students have read the lab book prior to coming to the section meeting.

The lab consists of a dedicated room with 25 Macintosh 6100 power PC computers with 20 Mb of memory, CD-ROM drives, and an AppleShare file server. Computers are arranged around the periphery of the room so that non-computer activities at the tables in the center can be conducted without distraction. The first three lab sections prepare the students to write a scientific mid-term paper. The CD-ROM software contains a management module (“Class Master”), earth data access, homework entry, and game problem modules. Students purchase a lab manual that provides them with instructions for the various section exercises. Students begin the first section by logging into the class management system (figure 2), which creates a database that will contain records of their activities. Class activities are accessed from an activities index and they begin entering the first homework. The lab manual and online help nearly eliminate the need for teaching students how to use the software. The data module (figure 3) allows students to plot elevation profiles between any two locations, plot earthquakes and quake cross sections, plot cenozoic volcano locations (on land), determine island ages, seafloor ages (latest version), measure heat flow, and access movies and still graphics illustrating views or facts about particular locations. This provides students with enough raw earth data to solve many of the problems of plate tectonics. Plate boundary types (using quakes, volcanoes, elevations, heat flow) and plate motion can be determined (using island ages/hot spots). More advanced studies can be conducted on slab dip, studying more complex plate boundary configurations, and comparing various plate boundaries at different geographical locations. A key component of this system is the class management software. Its purpose is to relieve the instructor and teaching assistants (TA’s) of routine grading activities, and to give the student ongoing feedback on his/her course grades. It allows us to assign and hold students accountable for weekly homework assignments and other activities, such as the geography game and the profile game, which are automatically graded. My experience has been that students will work very hard for points. When I was testing the first version of the homework software, several students worked long hours to get the maximum number of points, even though I told them that the software had a bug and it would be fixed soon.

The class management software also allows us to hold TA’s accountable for grading and entering hand-graded activities in a timely manner. All student grades are available to the instructor and TA’s, but a student only has access to his/her own entries, which solves a difficult

privacy problem involving the posting of student grades in public places. In addition, it allows us to use a larger number of activities to determine a grade. Student comments indicate that they appreciate the fact that their entire grade doesn't depend on a small number of curved exams. All assignments are graded on an absolute scale. This allows students to examine their current grade at any time during the course, which provides a strong motivating factor.

6. The Writing Assignment:

The initial motivation for the writing assignment was to require students to understand the material in more depth. Later on it became clear that it also motivated students to understand important elements of the science process (Kelly and others, 1999). These include asking what counts as a valid investigation, what is the difference between an observation and an interpretation, what data can be used to frame a scientific argument, how to actually write in the scientific format, and how to critique the writing of others.

The focus of the writing assignment is on selecting data from the extensive datasets of the "Our Dynamic Planet" CD-ROM to support the theory of plate tectonics. Students must choose a solvable research problem and gather data to support a model. This is very difficult for them because they do not know enough plate tectonics theory to pose a reasonable scientific question, much less how to present evidence to support an argument. Guidance is given by asking them to find evidence to support the generic, cartoon-like textbook drawings that illustrate plate tectonic geometries and processes. This gives them some security and a basis from which to start. It also requires them to learn the theory in depth and visualize the 3-dimensional structures of subducting slabs, transform faults, spreading centers, etc. at plate boundaries. The lab section activities consist of two preliminary writing exercises, group feedback and evaluation sessions, and discussions of how scientists select a problem, how evidence is used to support their theory or model, how observations are separated from interpretations, and how these elements are formatted into a scientific paper.

My goals, in the writing assignment, are for students to experience the following elements of science:

1. understanding background knowledge (the theory of plate tectonics)
2. asking a testable scientific question
3. selecting data and making observations

4. interpreting data to support a theory or model
5. presenting an argument
6. evaluating the work of others

In preparation for this assignment, students do shorter writing assignments which are critiqued during group activities in the lab section. By the third lab section, students have made and received feedback on an outline of their paper and are ready to write.

7. Implications for Distance Learning Designs

For the sake of this discussion, I divide the educational experience into three elements, diagrammed in figure 4. Each of these elements constitutes an important consideration for the design of network and distance learning courses (see McIsaac and Gunawardena, 1996 for a review of distance education and relevant research). They address both the factual content of science and the social context within which the learning environment (and science) operates. Most science courses address each of these to some extent. We are most familiar with the content element, which is the major focus of most science classes. A class also consists of a social component, where students meet each other (both during and outside of class) and discuss the concepts important to achieving the goals the class. The third element I call “presence”. It includes all interactions between the professor and students, including the modeling of behavior and thought processes of the professor. The professor is a role model with which some students will identify, and which may inspire them to go further with the subject. In the following paragraphs, each of these elements will be discussed in the context of both the traditional lecture class and a distance learning class. For the purposes of this discussion, I distinguish between a "network" class, in which students are local and have the opportunity to attend lectures or go to the professor's office hours, and "distance learning", where face to face opportunities are rare or nonexistent. This discussion is not a review of research on the subject, which is quite sparse and not subject to general agreement. I appeal to the research references already made, common sense, and common experience communicated through discussions with my colleagues. Much of the following discussion will be true for some students, but not for others. The effect of approach on different kinds of students was chronicled in Tobias's book: “They're Not Dumb, They're Different” (Tobias, 1990), where the experiences of bright and capable students who chose non-science majors were studied as they took physics and chemistry courses.

7.1 Content:

This element is most familiar to us. It includes the facts, figures, concepts and theories that students repeat back to pass the traditional mid-term and final exams. It may also include techniques such as writing skills and use of analytical and problem solving techniques. The lecture component of traditional lecture classes is actually quite weak in this area, as previously discussed. The doubting professor can easily verify this by assigning a minute paper at the end of the lecture asking: a) What was the major point of today's lecture, and b) What is the major question you have regarding today's lecture? Content retention is enhanced when students are required to conduct activities that actively engage them in the subject matter of the course. Examples are answering questions about the subject, working problems, making presentations, or writing. The instructor of the large lecture course is quickly overwhelmed by numbers when giving assignments. The instructor is driven to limit the number of assignments and to make them easy to grade. Unfortunately, this leads to decreased effort by students who often must prioritize ungraded activities with the demands of other classes. Based on student feedback and direct observation, I have found that students work much harder when their work is graded. Network methods can provide a powerful means of delivering content-based games and short exercises that can be automatically graded. This relieves the instructor and teaching assistants of tedious grading in favor of a smaller number of substantive assignments that engage the student more deeply.

One of the important resources that allows students to focus on the process of science is the "Our Dynamic Planet" CD-ROM. It contains an assortment of relevant databases that are immediately accessible without searching, downloading, reformatting, or waiting. It also provides some constraints on the scope of their investigation. This was underscored by the difficulty students had in selecting a problem to work on, until I implemented a 1 page assignment requiring them to all focus on a selected plate boundary region. Inquiry activities for large general education classes require compilations of a range of relevant databases with self-documented viewers that allow students to quickly access the critical data for their investigations. It is also important to design data viewers for compatibility with other class and network tools so that students do not have to learn a multitude of new interfaces.

7.2 Social Context:

A conventional class consists of a social component, where students meet each other (both during and outside of class) and discuss the strategies and concepts important to achieving the goals the class. Science itself also operates within a social context, which concerns itself with how science is conducted, what counts as a valid problem, how to use evidence, etc. Practicing scientists participate in workshops, write papers, write proposals, and present their findings at meetings. It is within this context that scientists give credence to, and validate, scientific information. In order for students to understand the process of science, it is important to expose the student to the practicing scientist's social perspective. Creating or supporting a social context for a course that embodies or simulates that of the practicing scientist is an important way of teaching science practice.

In site-resident courses, lab sections can support the development a science practice oriented social environment. The shortcoming of relying on lab sections to do this, for large classes, is that they are usually taught by teaching assistants with limited experience, so quality may vary. In a network environment, bulletin boards, listserves and chat groups can fill some of this need. Network technology provides an opportunity for students to publish their work for peer review. Asking students to critically review others' writing should improve their own writing and involve them in another component of the science process. Currently, I know of no web-based software that implements this kind of social environment at a simple enough technical level to be practical for students with only basic computer skills.

7.3 Presence:

For the fortunate reader, there was a "special" professor who somehow inspired her/his decision to enter a field of specialization. An outstanding lecturer can be engaging, as well as model the thought processes of practicing scientists. Less tangible is the students' *identification*, in the psychological sense, with the professor. A student may like the professor and want to emulate her/him, motivating further study in the field. Student questions can get asked and answered through email, but how important is an actual live human being as a teacher? The student may also identify psychologically with the subject matter, as it is reflected in the professor's thought processes as he/she presents the material. These effects will undoubtedly be strongly dependent on the personality, attitudes and motivations of the particular student, and provides interesting subject matter for education research.

To carry this a bit further and consider how network learning could improve a conventional lecture class, it is interesting to imagine a class where each student routinely enters the lecture hall having already read the relevant textbook chapter and has performed a short homework activity on the subject of the lecture. The focus of the lecture could be completely different. I would predict more questions from students, more class discussion, more talk about the meaning and significance of the content, and higher student engagement overall. I expect that there would be general agreement that this is an unrealistic expectation, even for upper division majors. However, if students were held accountable for the material through online, automatically graded homework assignments, better student preparation for lectures should be achievable (assuming universal student access to the internet).

8. Summary

One of the important purposes of this paper is to focus on good teaching practice and how this might affect the design of network and distance learning classes. I have discussed a typical large class in the context of three basic components: content, social context, and presence. Network approaches are likely to provide a substantial improvement over lecturing for the content component. The popularity of internet chat rooms, listserves, and email suggest that the social component might also be well served by network approaches. But, experience teaching a variety of students in a large class setting suggests that this will not be true for all students. Technology developments in peer review software and simple (technically) posting of student work to the network, combined with bulletin board, chat and listserves, will support the development of a network social context. The effect of the presence of a live professor will be the most difficult to match on a network. Again, experience suggests that this will depend strongly on individual student needs and goals, so we must not lose sight of the fact that certain kinds of students may not gain the same benefits of network learning that others do.

Much of what I have suggested should be supported by additional education and cognitive research on network classes. Our success in designing and creating effective network and distance education learning environments will surely have an enormous impact on the science literacy of our citizens in the next millenium.

Acknowledgements

I would like to acknowledge many helpful discussions with Prof. Gregory Kelly of the UCSB Graduate School of Education, Prof. Charles Bazerman of the UCSB English Dept., Prof. Richard Mayer of the UCSB Dept. of Psychology, and my other education oriented colleagues at national geoscience meetings and committees. This work has been generously supported by the National Science Foundation (DUE-92564192 and DUE-9455758) and the UCSB Office of Instructional Improvement.

References

- All-University Conference on Teaching and Learning Technologies and the Present and Future of the University, (1997), Proceedings, Mar. 25-26, 85pp
- American Geophysical Union, (1997). "Shaping the Future of Undergraduate Earth and Planetary Sciences Education: Innovation and Change Using an Earth System Approach", 76pp
- Brooks, J.G. and M.G. Brooks, (1993). In Search of Understanding, The Case for Constructivist Classrooms, ASCD Publications, ISBN: 0-87120-211-5, 136pp
- Duschl, R.A., 1990. Restructuring Science Education, The Importance of Theories and their Development, Teachers College Press, New York, ISBN 0-8077-3005-x, 154pp
- Gardner, M.Greeno, J.U.G., Reif, F., Schoenfeld, A.H., diSessa, A., & Stage, E. (Eds.). 1990. Toward a scientific practice of science education. Hillsdale, NJ;Lawrence Erlbaum Associates.
- Kelly, G.J., Chen, C., and Prothero, W. 1999. The epistemological framing of a discipline: Writing science in university oceanography, Manuscript submitted to the Journal of Research in Science Teaching.
- Linn, Marcia C., 1992. Science Education Reform: Building on the Research Base, Jour. Res. in Science Teaching, 29(8),821-840.
- Linn, Marcia C., Establishing a research base for science education: Challenges, trends, and recommendations. *Journal of Research in Science Teaching*, 24(5),191-216.
- McIsaac, Marina S., Gunawardena, Charlotte N., 1996. Distance Education, in Handbook of Research for Educational Communications and Technology, Simon and Schuster Macmillan, New York, 1261pp.
- Meyers, C., Jones, T.B. 1993. Promoting Active Learning, Jossey Bass, ISBN 1-55542-524-0, 192pp.
- National Research Council, 1996. From Analysis to Action, Undergraduate Education in Science, Mathematics, Engineering, and Technology, National Academy Press, Washington, D.C., 38pp.
- National Research Council (1996). National Science Education Standards. Washington D.C.: National Academy Press, 262pp.
- Pollio, H.R., 1984. What Students Think About and Do in College Lecture Classes. Teaching-Learning Issues no. 58. Knoxville: Learning Research Center, University of Tennessee.
- Prothero, W.A., 1995. Taming the Large Oceanography Class, Jour. of Geological Education, 43, Nov. 1995.
- Shymansky, J.A., Kyle Jr., W.C., & Alport, J.M. 1982. How effective were the hands-on computer programs of yesterday? Science and Children, 20(3), 14-15.
- Tobias, S., 1990. They're Not Dumb, They're Different. Stalking the Second Tier, Research Corporation, Tucson, Arizona, 94pp.
- Verner, C. and Dickinson, G., 1967. The Lecture: An Analysis and Review of Research, Adult Education, 17(2),85-90.