WHY I TEACH: A STATEMENT OF TEACHING PHILOSOPHY

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As a working scientist teaching young minds to think scientifically, I am very fortunate to be entering my field at a time when scientific knowledge and computer literacy are at a premium among university students, particularly in the United States and other countries of the developed world. New knowledge and technology continually expand the content which we deliver and the skills we impart in college science classes. My early efforts at teaching have benefited from access to the latest instructional technology and from fresh content acquired by attending scientific meetings and reviewing new textbooks and instructional materials. I have made use of my own research results to teach some topics, and I involve students in my research whenever that is practical and beneficial to their education.

Even while flush with new scientific knowledge, I have always emphasized certain fundamental principles of scientific method and critical thinking, which have deep roots in human intellectual history and were introduced to me early in my own undergraduate education. The deep intellectual roots of earth science methods seem particularly significant to me now that I have acquired some experience with how my students learn and sometimes fail to learn the content, skills, and values that I am trying to teach. What I most want students to learn from my teaching is not the particular knowledge tested on quizzes and exams but how to think more scientifically about the
various problems and concerns they will encounter as more advanced students or as citizens of the rapidly changing world that we all live in.

**SCIENCE AND CRITICAL THINKING**

While scientific research is by no means the only way in which people collect information and form opinions about the world they inhabit, I do believe that our core scientific principles and values are universal and form a basis for critical and rational discussion. Recent texts listing values of critical thinking (Bassham et al., 2005; Moore and Parker, 2007; Niewohner, 2006; Paul, 1993; Paul and Elder, 2000) are quite comprehensive and encompass all that I had arrived at myself through perusal of many philosophical systems, including some authored by thinkers from Asia, Africa, and other areas not traditionally considered to be sources of "rational" thought (e.g. Hayward and Varela, 1992; Wiredu, 1998; Zajonc, 2004). For teaching, integrity is perhaps the highest priority. Students learn values and habits of thought by example, and to refuse to entertain questions of value and human purpose merely inspires our students to do likewise. With respect to environmental, medical, and other concerns that are particularly close to the special interest of working scientists, refusing to pass judgment also leaves those issues to be decided by those who lack current information or have narrow perspectives (Stevenson, 1954).

Given that we cannot and ought not to avoid ethics and politics while teaching science, my approach is to tolerate a wide diversity of opinion among my students while encouraging them to empathize with those holding opposite positions. Empathy and fair-mindedness are intellectual virtues that we cultivate in critical thinking (Paul, 1993; Paul
and Elder, 2000) while at the same time we continually challenge superficial or hasty answers in ethics and politics, just as we do in natural science. Nearly 100 years ago, this virtue of humility intrinsic to the scientific method was remarked by the great American pragmatist, John Dewey (1916, p. 189). We suspend judgment and subject our opinions to rational discussion just as in the scientific method we subject our hypotheses to experimental testing. We do so having confidence that reason and logical argument are universal skills and faculties, even though they may not in fact be equally distributed among students in a class or citizens of a community or a nation.

Philosophically, I have always been comfortable addressing theoretical questions or ethical and political topics in my science classes. It has taken me several years as a temporary or part-time faculty member since obtaining my Ph.D to develop teaching strategies that challenge students to think critically and express their opinions in logical arguments. When teaching larger classes of 50 students or more, I prefer to use an interactive format in which students are assigned to small discussion groups. Both group discussion and writing assignments develop respect for reason as well as autonomy, a virtue which is not always nurtured by science education as much as it is by liberal arts.

Rather than simply ask for a "term paper," I typically assign several shorter writing assignments that require careful reading and logical argument for or against an opinion or hypothesis. I do use computer-graded multiple choice tests to assess foundational material, but I also include reasoning problems and essays in my examinations. In my laboratory sections, I typically design or select exercises that challenge students to apply concepts and write out their interpretation of a map feature, bedrock structure, petrographic texture, and so forth. I grade the laboratory reports based
upon logic and following procedure as much as getting the right answer. Foundational material is valuable only if the students retain it for several semesters, and the sort of short-term memory recall tested in multiple choice tests is not nearly as important for a successful science career as is perserverance in the face of difficulties, obstacles, and frustrations. For challenging students to persevere and show courage in their thinking, I have had best results using take-home essay examinations or examinations taken in class on essay topics assigned several days prior.

As was pointed out as early as the first decade of the 20th century (Mead, 1906), modern colleges and universities encourage specialization rather than integration among the sciences. Whether in terms of academic departments, courses offered, or topics presented in an introductory course, we tend to introduce our students to science "through one door at a time (Mead, 1906)." Students need and deserve a different approach, one that exposes them to the big picture of scientific understanding, what Mead awkwardly referred to as science's "complex interrelation with a mass of other things (Mead, 1906)."

Part of what I enjoy about teaching environmental geology or environmental science is the opportunity to demonstrate practical applications in the community where students live. Environmental problems also have ethical and political dimensions which challenge students' critical thinking skills and attract many who would not otherwise take much science (Busse et al., 2007).

**FUNDAMENTAL IDEAS ABOUT EARTH SCIENCE**

For geology or geography majors, it may not be as important to experience Mead's "mass of other things" as it is to be taught, as Whitehead (1929) would have it, a
few, important "main ideas" about earth science. These main ideas or underlying principles that give science structure (Bruner, 1960, p. 31; Matthews, 2003) will be not only the most important to remember but also the most useful to students in their future education and careers. Personally, most of what I know and teach about in geology can be boiled down to four fundamental ideas, all of which are related to some extent to ideas which are also used in physics, chemistry, or biology. The most fundamental idea, particularly for teaching earth science as an integrated field, is that of lithospheric plates formed at midocean ridges and subducted in trenches (Cox and Hart, 1986). At least as fundamental to doing geology today is the exponential decay of a radioactive isotope to its daughter product(s) at a constant rate (Dickin, 1995; Faure, 1986). In fact, it took dating the rates of seafloor spreading by decay of potassium to argon to actually prove plate tectonic theory. Without isotopic dating methods, earth history would be based upon relative rather than absolute dating and we would be teaching a very different course in historical geology.

Two remaining fundamental ideas relate more specifically to my own areas of research. One of these is the conservation of matter and energy, intimately related to geomorphological principles such as Darcy's law for calculating groundwater discharge (Fetter, 2001; Hubbert, 1969) or the "quasi-equilibrium" adjustment between channel dimensions, gradient, discharge, and sediment supply in river channels (Knighton, 1998; Schumm, 1977). The more advanced student will of course learn that the picture is not really as simple as suggested in these classical models. In order to account for conditions of pressurized flow, for example, we must supplement the simple mechanical calculations of energy and force in fluids by using the Navier-Stokes equations which include terms
for viscous forces acting inside a fluid (Allen, 1997). Mechanical models of physical processes and balanced equations for chemical reactions are used throughout earth science, serving as vehicles which carry forward the uniformitarian research project begun by James Hutton, the father of geology (Dean, 1992; Grant, 1979; Hutton, 1795; Playfair, 1822).

A final fundamental idea which plays a central role in both my teaching and my research is that soils are "functions" determined by the state of five factors - climate, organic matter, parent material, relief, and time (Birkeland, 1999; Jenny, 1941). Jenny's state factor model is an early statement of many of the objectives which we continue to pursue in soil "biogeochemical" studies. The challenge is always to hold as many factors as we can constant while observing variations in one of the others, as is done for example in soil "chronosequence," "toposequence," or "climosequence" studies (Birkeland, 1999). While few of my current students have an opportunity to conduct such detailed studies, I do cover the different soils found in Georgia and other parts of the world in sufficient detail that they understand principles of classification and how profiles develop in response to changes in each factor. Current field and laboratory methods applied to modern soils, particularly the examination of soil thin sections under the microscope (soil micromorphology), can also be used to study paleosols, soils that formed under landscapes of the past (Retallack, 1990). Once again, the specialized research serves as a vehicle advancing the general project of understanding the present as a key to the past (Geike, 1905, p. 299; Hutton, 1795; Lyell, 1830).
BOLD HYPOTHESES ABOUT THE EARTH

What most captures the popular imagination is not the slow, daily workings of planet Earth, nor is that what typically prompts an undergraduate student to take their first geology course. Bold hypotheses about cosmology, deep time, extraterrestrial life, and mass extinctions are presented in nearly all earth science and environmental science textbooks with only cursory mention of the detailed empirical studies that have convinced leading scientists of their plausibility. It is the job of a college science teacher not merely to titillate or entertain young minds with the sorts of outrageous hypotheses that have proliferated since they were advocated so strongly by William Morris Davis (1926). We must also try to provide enough detail so that students can determine for themselves whether the scientific consensus in support of a hypothesis is based upon the detailed "examination of the present state of things" advocated by Hutton (1795).

Learning to think critically becomes extremely important when considering the evidence for and against such bold geological hypotheses as: a snowball Earth caused by global glaciation during the Precambrian (Hoffman and Schrag, 2002; Hoffman et al., 1998; Kirschvink, 1992), salinity crises and other sudden changes in the chemistry of the oceans (Berner et al., 1983; Hsü, 1983; Stanley, 2000; Stanley and Hardie, 1998, 1999), mass extinction events - the demise of dinosaurs at the Cretaceous/Tertiary boundary and the earlier Permo-Triassic event (Alvarez, 1997; Alvarez et al., 1980; Benton, 2003; Erwin, 2006; Ward, 2000), meteorite impacts - the recently discovered Chesapeake Bay crater of late Eocene age (Poag, 1999; Poag et al., 1994), the Ries crater of probable Miocene age (Dennis, 1971; Horn, 1972; Shoemaker and Chao, 1961), and the Chixculub crater identified as the cause for K/T mass extinction by Alvarez et al. (1980),
supervolcano eruptions responsible for the Millbrig and Kinnekulle ashfalls of Ordovician age (Bergström et al., 2004) as well as the Pleistocene ash from calderas in Yellowstone and other locations throughout Mexico and the western United States (Lowenstern et al., 2006; Sarna-Wojcicki and Davis, 1991), megafloods in the channeled scabland of eastern Washington state (Baker, 1987; Bretz, 1923, 1928), global cooling episodes such as the relatively recent Younger Dryas event approximately 11 thousand years ago (Alley, 2000; Broecker et al., 1989; Peteet, 1995), or the rapid evolution of Homo sapiens when the first hominids migrated out of Africa (Stringer, 2003; Tattersall, 1995; Cann et al., 1987).

Textbook explanations of the scientific method read like a simple recipe in a cookbook and are not very helpful when we are actually trying to come up with a good hypothesis or decide between several competing hypotheses for a single geological feature or phenomenon. In his classic paper which should be read by every advanced student of geology, Chamberlin (1890) admonishes earth scientists to entertain multiple working hypotheses rather than rushing to favor a single "ruling hypothesis." Even when we have considered multiple hypotheses and designed appropriate tests for each using actual field observations or laboratory experiments, however, there is no guarantee that we will accept a true hypothesis rather than claim to have successfully rejected it. The great American geologist Grove Karl Gilbert was wrong at least once, for example. Gilbert rejected the meteorite impact explanation for Arizona’s Meteor Crater based upon volume calculations and a magnetic survey (Gilbert, 1896; Schumm, 1991, p. 23). In Gilbert's case, it may have been an overly stringent uniformitarian approach characteristic of 19th and 20th century geology that biased him against accepting a correct hypothesis.
I keep an open mind with respect to the role of rapid, even "catastrophic" events in Earth history, encouraging my students to do likewise. I think that we remain true to the spirit of Hutton and the other founding earth scientists as long as we use direct observation to test the latest hypotheses whenever possible. Stratigraphy does provide us with a record consisting primarily of gaps, fits, and starts rather than continuous sedimentation governed by slow, gradual processes (Ager, 1973; Anders et al., 1987; Sadler, 1981). Some role for extreme environments and rapid rates of change is consistent with uniformitarianism as practiced by Hutton, who is otherwise well known for describing angular unconformities that slice up the layered sedimentary and metamorphic rocks of his native Scotland.

DIRECT OBSERVATION AND ENVIRONMENTAL PRAXIS

Geology shares with botany and zoology an ontogeny in that cluttered cabinet of "natural history" which lives on in small regional museums and the collections of amateur naturalists of every stripe. Like practitioners of these other "field sciences" (Allen, 1978; Kohler, 2002), geologists give priority to direct observation and description of nature's diversity. By contrast, these are not typical research priorities in physics or chemistry and are dismissed as "merely intuitive" understanding in mathematical research (Davis and Hersh, 1998, p. 391-399). Fieldtrips are essential for teaching geology and, from a pedagogic perspective, they are a good opportunity to challenge students with strong aptitudes for visual, tactile, and kinesthetic learning (Dunn, 1996; Dunn and Dunn, 1993; Tate, 2006). Field experience does more than simply provide examples of objects and concepts that are taught in lectures and labs, it makes concepts
tangible and allows students to envision how objects are formed by fundamental earth processes (Compton, 1985, p. 25-27; Frodeman, 2003, p. 95-115; Skinner et al., 2004, p. 5).

In presenting her list of fieldtrips that every geologist should take in their lifetime, Rossbacher (1990, 2005) emphasizes the powerful influence of field experience on one's success as a teacher of geology. Students find a teacher's firsthand experience inspiring, particularly those students who may have less aptitude for purely verbal delivery of foundational material. Fieldtrips do need to be structured so as to make an effective use of time away from the classroom or from student work and study responsibilities outside of class. Although I typically prepare a worksheet with questions about outcrops or landscape elements that we observe in the field, I also like to ask some more open-ended questions which challenge students to display critical thinking and creativity (Bartley, 2007; Busse et al., 2007; Padilla, 1991).

In teaching advanced classes, I build upon students' previous field experience and I begin to make them aware of the limited visibility of the rock record in natural outcrops, highway and railroad cuts, or quarries and mines (Nichols, 1999, p. 290-298; Skinner et al., 2004, p. 5). Rocks that are not exposed at the Earth's surface can be sampled through various methods of subsurface investigation, with drilling and deep excavation giving us the most direct observations. Rarely is a complete core recovered by drilling, however, and subsurface structural features and stratigraphic contacts are always more difficult to reconstruct. To supplement fieldtrips, and particularly when it is not possible to introduce students to drilling equipment first hand, I teach through preparation of stratigraphic logs and fence diagrams, physical models made out of folded
paper or modeling clay, or interactive computer graphics (Libarkin and Brick, 2002).
What is most important in the design of laboratory and homework exercises, I think, is
that students be rewarded for following procedures and keys correctly even if they do not
arrive at the correct answer or result. I also believe strongly in using real data wherever
possible and teaching procedures that are only slightly simplified from those which are
standard in current research.

When teaching hand sample identification, outcrop description, and basic field
mapping we always emphasize direct observation. In both industry and academic
research, however, geologists also observe rocks indirectly by means of various
geophysical instruments (Keys, 1990; Milsom, 2003). Whether the instrument is lowered
into a borehole, making contact with the land surface, or mounted on a remote platform
the result is the same. Properties are observed that are different from what can be sensed
directly, and many of the properties that would be recorded in outcrop can only be
inferred. In the case of a few methods such as seismic monitoring and ground-penetrating
radar, techniques have been developed to filter the geophysical data so that we can
actually obtain an image of subsurface features and stratigraphic contacts (Conyers,
2004; Milsom, 2003). We may not be able to determine the exact composition or detailed
properties of the rocks, however, unless we are able to "ground truth" the geophysical
results.

Geology actually makes use of many other methods of "indirect" observation that
most of us take for granted. We look at rocks through hand lenses or simple binocular
microscopes and then move up to petrographic and scanning electron microscopes. For
mineral identification we use x-ray diffractometers, and for chemical and isotope
analyses we use various spectrometers. The scientific study of the Earth and Earth materials is built upon direct observation but also ventures far beyond it. I think that it is important for students to understand that technology continually gives us new experiences, "new" not only the sense of more (quantity) but in the sense of "different" and more diverse (quality). For example, there is the exciting venture known as "planetary geology," in which robotic platforms were recently sent to Mars equipped with sophisticated versions of several instruments that geologists commonly employ in the study of the Earth and Earth materials (Squyres et al., 2003).

As a field science, geology demands a combination of theory and practice which some philosophers and social scientists have referred to as "praxis" (Habermas, 1973). The theory includes "first principles" of physics and chemistry, but our hypotheses always refer to specific Earth materials and events in Earth history. We sometimes test those hypotheses under controlled conditions, such as the flumes used to model natural rivers. More often than not, however, we work by comparing objects and events with one another and with their surrounding environment. We use the physics and chemistry to explain the state of an object or to gauge the rate for a sequence of events. Following the direction set for geochemistry by Forbes (1868) back in the 19th century, the chemistry and physics are most valuable when they give an explanation or an insight into a geological problem experienced in the field (Brock, 1978).

In addition to fieldtrips, stratigraphy projects, and remote sensing exercises, Earth science educational praxis is greatly advanced by experiments with simple devices such as stream tables (Lillquist and Kinner, 2002), groundwater simulators (Gates et al., 1996; Trop et al., 2000), and seismic shaking models (FEMA and AGU, 1994). Students see
that scientific knowledge can be used to diagnose and sometimes to solve environmental problems. Environmental science and environmental geology classes are currently popular with students, emphasizing the "practice" aspect of the praxis paradigm (Fawcett et al., 2002). I think of praxis as a general approach or philosophy, applicable to teaching physical geology, stratigraphy, or geomorphology as well as environmental and hydrogeology courses.

TEACHING AND LEARNING IN THE DIGITAL AGE

The practice of education has been evolving at a rapid rate in recent decades, thanks to our increasing use of electronic devices for communicating and for storing and processing information. In terms of teaching philosophy, our goals in education remain more constant than do our means of achieving those goals. Nonetheless, our concept of what it means to be an educated person today certainly does involve familiarity with computers and other technology which we all now use to read, write, calculate, and visualize. This would not have been true fifty years ago, when film and television media were already spreading throughout the civilized world but were primarily used for entertainment, advertising, and politics.

Much teaching is actually done today through computers on the internet, as "distance learning" (Keegan, 1990). Even for those of us who still deliver lectures to students in a classroom, however, computers are commonly available to project textual and visual material during our lectures. Students also commonly bring computers, programmable calculators, cellphones, and other digital devices to class, some of which they even purchase specifically for college. I have been using Microsoft Powerpoint® to
prepare and deliver lectures since I started teaching geology at Georgia Perimeter College in the fall of 2002, and I used technology when presenting talks at meetings prior to that beginning in 1996. For me, this has been a trial and error process with many of my lectures now having been developed to a stage where I only make a few changes each semester. I use the distance learning program VistaWebCT as well, providing my students with syllabi, course schedules, grades, and all of my lectures through the internet as either Microsoft Powerpoint® or Adobe PDF® files. My familiarity, experience, and investment in educational technology is fairly typical for a junior faculty member today, I think.

Faculty and students do vary with respect to the use of technology for learning, particularly with respect to their use of visual materials. Geologists often opine that ours is a "visual" science in that maps, cross-sections, photographs, photomicrographs, and data plots are used to explain our methods as well as to illustrate key concepts (Rudwick, 1976). The power of a strong visual presentation has long been recognized in other scientific fields as well, although many teachers and publishers for elementary and secondary school students question the need for visual materials. One survey of studies of children learning to read found, for example, that "pictures used as adjunct aids to the printed text, do not facilitate comprehension (Samuels, 1970)."

Whether in print or in a Powerpoint® lecture, the design of visual materials and of the text or speech that they accompany contributes significantly to their effectiveness. As Peeck (1994) concluded in her study of 45 college students at Utrecht University, very little of the instructional potential of illustrations is generally realized in daily educational practice. Drawing upon psychological theories of visual and multimedia learning (Clark and Paivio, 1991; Kulhavy et al., 1985; Leavitt, 2007; Mayer, 2005; Schnotz et al., 1994), I select, create, and utilize my visual materials with the goal of enabling my students to construct a mental model or "schema" of whatever concept or procedure I am trying to
teach. This approach to visual learning is one to which I was first introduced by the authors and editors of the Wiley "Visualizing" series, for whom I served on several faculty focus groups. During the fall of 2006, some students in my Physical Geology (GEOL 1121) class at Georgia Perimeter College also read and submitted online reviews of the Visualizing Geology textbook (Murck et al., 2008).

Emphasizing the effective use of "virtual memory" (Baddeley, 1992) while minimizing "cognitive load" (Chandler and Sweller, 1999), Wiley "Visualizing" consultant Matthew Leavitt has made the cognitive theory of Mayer (2005) accessible to the series editors, textbook authors, and teachers who are making use of the rich library of photographs, maps, and digital videos of the National Geographic Society. The general approach is to combine speech, written text, static images, and video in an integrated manner, drawing upon a student's prior knowledge to engage their mind and help them to build strong mental models.

![Figure 1: Cognitive Theory of Mayer (2005)](image-url)
The figure from Mayer (2005) on the previous page represents the intended integration, which will of course be achieved differently when delivering a spoken lecture as opposed to a written handout, textbook, or research paper. As teachers, we can minimize extraneous cognitive load by choosing textbooks and teaching materials which contain precisely those concepts and examples which we plan to emphasize in our own lectures. In spite of the contributions which the Wiley "Visualizing" series has made to my own teaching philosophy, therefore, I maintain relationships with other publishers and continue to use several other textbooks, particularly for my advanced courses on geomorphology or stratigraphy. Computer programs can also be extremely useful both for teaching and for familiarizing students with methods and procedures they will need to use in professional scientific research. When choosing software to use in teaching, some important considerations which I keep in mind are:

(1) How much time must I myself and my students spend learning the program before it starts delivering the promised content (i.e. Does the program contain "extraneous cognitive load."

(2) How much does it cost?

(3) Are other colleges and universities using the software?

(4) Is the software used by government and/or private industry?

Few computer programs would receive a strong positive score in all of the above areas. Geographical information systems such as ArcGIS® (ESRI, 2006), for example, require considerable time investment on the part of the user before they begin to provide
independent educational rewards. Nonetheless, ArcGIS® and the other ESRI products are widely used by both government and private industry. Students recognize the career opportunities afforded by GIS training, and many faculty themselves obtain grants from ESRI for research projects that involve their students and enable them to apply newfound geographical knowledge (Sanders et al., 2001). I have personally used ArcGIS® in my consulting for archaeologists, and I plan to do so for future research projects in which my students are involved.

There are several other computer programs which are "industry standards" for professional geologists. AQTESOLVE® (Hydrosolve, 2007), a program for hydrogeological modeling of groundwater aquifers, is now distributed with a leading hydrogeology textbook (Fetter, 2001). For making most of the ternary plots used by igneous petrologists, there is IgPet (Carr, 2005); and for creating x-ray diffraction patterns similar to those that result from scanning slides prepared with specific clay minerals or with mixed-layered samples there is NEWMOD (Reynolds and Reynolds, 2005). I would not introduce students to any of these programs until after they had already mastered certain of the calculations and graphing techniques so that they can verify and interpret the program output using their own data.

In many cases, computers do enable us to save time in making calculations, perform operations consistently on large data sets, and check student work before proceeding to present or publish research results. Plotting strike and dip measurements and other structural data on a lower hemisphere projection is particularly time-consuming and difficult for many students to perform consistently. Computer programs such as Stereonet (Almendinger, 2003) are consequently indispensable for structural geologists
and geophysicists dealing with orientation data, and such stereoplot programs can also be helpful to advanced geology students conducting their own research projects. Although typically beyond the budget of college geology departments, Rockware (2006) provides an entire Rockworks™ suite of programs which organize well logs and field descriptions, correlate stratigraphic columns, balance sections, and even perform "backstripping" based upon structural evidence for compression, folding, and faulting. WinFence (GAEA, 2007) is a more affordable program for accomplishing many of the same tasks. WinFence also takes up less server memory and is easier for students to learn than the equivalent programs in the RockWorks™ suite.

Structural geology is one of the more challenging subjects to teach college students, and visual learning materials such as computer animations are often helpful in showing the structure of objects and their relationships to other objects (e.g. Dwyer, 1994, p. 384). I currently use short Macromedia Flash® animations embedded within my Powerpoint® presentations. There are also programs such as Geo3D (Kali and Orion 1996; Kali et al., 1997) which have been specifically designed by geologists collaborating with software designers to teach students structure concepts. While it is intended for high school or even middle school students in Israel, Geo3D progresses from simple cross-sections of anticlines and synclines to complex folds offset by normal faulting on the Menasheh Plateau and the Judean Mountains.

Most of us who were educated prior to the widespread availability of computers and other electronic devices in classrooms, dorms, and home offices tend to regard graphics, videos, and computer animations as "aids" to use in teaching concepts that can be independently articulated in written or spoken language. Several more ambitious
thinkers have instead proposed that we aspire to a uniquely "visual literacy" (Debes, 1969; Seels, 1994), an ability to communicate with images and perform various uniquely visual scientific tasks. To some extent, this is already taking place in specific fields. An early example would be the use of flight simulators to train pilots, and graphic work stations and computer images are now widely used for remote sensing and advanced microscopy. "Virtual reality" models which enable students to rotate geological maps and view them from any direction are currently being actively developed by Stephen Reynolds of Arizona State University. Virtual reality experiences enable a student to see how geology relates to topography, cities, and other features on the land surface (Reynolds, 2007), possibly extending their knowledge above and beyond what can be taught through written or spoken language.

Student (and faculty) enchantment with the power of visual presentation, visual experience, and perhaps even visual "language" must not be allowed to take the place of thorough education in science fundamentals. As was recognized more than a decade ago in national surveys (Paulos, 1988; Snyder, 1990), many students beginning college education today in the United States lack the basic numerical literacy that they need to be able to grasp Earth science concepts without a certain amount of remedial instruction. I begin with units of measure, using examples of both very large and very small objects and introducing our geological "deep time" perspective on the Earth and the universe as a whole. As we move on to study rocks and minerals, alert students are sometimes able to recall the angstrom (Å) unit when I discuss the radii of the cations and anions in common molecules. A select few may even remember which way to move the decimal place in
scaling down from the angstrom to the currently popular nanometer of the "nanoscience" world.

Geologists share with chemists and atomic physicists an interest in the very small objects which are the building blocks of matter, but we also share with astronomers a cozy familiarity with large numbers. Although Carl Sagan may never have uttered the words "billions and billions" on his television program *Cosmos*, he did introduce us to a vast universe populated with around 100 billion galaxies and 10 billion trillion ($10^{22}$) stars (Sagan, 1997). Large numbers can be used for time as well as space, and there at least 4.6 billion ($4.6 \times 10^9$) years between today's events and the events which created the Earth and other solid planetary bodies in our solar system (Dalrymple, 2004). Using the Systeme Internationale (SI) unit for time, we humans all live around two billion seconds (deGrasse Tyson, 2000; Taylor, 1995).

Puzzles about measurement and unit conversions not only entertain the easily bored undergraduate, they demonstrate the common numerical basis of all scientific inquiry and the importance of numerical literacy for processing information in a modern scientific culture. Many of our descriptive terms in scientific fields are essentially shorthand for the values of fundamental dimensions such as mass (M), length (L), and time (T). In geology, for example, an intrusive igneous rock body which has an area greater than 100 km$^2$ ($L^2$) is referred to as a "batholith" while a smaller intrusion would be a stock. Stone Mountain, familiar to all students in the Atlanta suburbs where I currently teach, qualifies as a stock but not a batholith.

Some memorization of constants and unit conversions is necessary for geology as for most scientific fields, but numerical literacy is really a matter of feeling comfortable
with numbers and knowing how to enter them and interpret them correctly as values for variables in equations (Bridgman, 1922). Most students have heard of a light year, for example, but few are able to explain how the constant speed of light, 186,000 miles per second (L/T), makes it possible to calculate a constant distance, about 6 trillion miles, which light travels in one year (Moseley, 2001). I find that students with severe "math anxiety" sometimes benefit from solving problems with other students in small discussion groups. I also take advantage of students' familiarity and interest in using both computer spreadsheet programs such as Microsoft Excel® and programmable calculators to develop numerical literacy and quantitative skills that are crucial for more advanced college work in geology and other scientific fields.

For non-traditional students who are not as familiar with digital technology, there are good reference works on Excel® (e.g. Conmy et al., 2006) in addition to Microsoft's online help. Many colleges and universities also now introduce students to Excel® in a one credit hour course on computer concepts or "digital literacy." I have developed several exercises myself which emphasize sorting columns of data, calculating with simple formulas, and producing x-y scatter plot graphs. One such exercise is a simple calculation of the linear increase in lithostatic pressure with depth in the Earth's crust. An interesting application of the "balance sheet" design of Excel® is to have students work as a group to develop a quantitative model of all the reservoirs in the hydrological cycle (Rose, 1997). In the Historical Geology laboratory course at Georgia Perimeter College (GPC), we teach grain size analysis using an exercise in which the mean grain size, sorting, skewness, and kurtosis are all calculated in an Excel® spreadsheet by the students themselves (Anderson, 2005). In my Environmental Science class at GPC, I have taught
descriptive statistics for several years now using data on water chemistry from wells in both the Piedmont and the Coastal Plain of Georgia, much of it obtained from U.S.G.S. websites. I also encourage students to use Excel® to complete the flood frequency analysis I assign of 30 years of record from the Conestoga River at Lancaster, Pennsylvania.

My choice to use Microsoft Excel® to teach quantitative methods is consistent with my teaching philosophy, in that it makes use of a tool with which many of my students are already familiar and will continue to use when they are no longer my students. Errors have been found in some of the Excel® formulas for statistical functions (Burns, 2006; Goldwater, 2007; Simonoff, 2006), and spreadsheet calculations should be checked carefully before using the results in academic research. Furthermore, some quantitative methods which are fundamental to geology are not easily adapted to either spreadsheets or programmable calculators. I have students plot chemical data on basalt compositions in an AFM ternary plot, for example. They can use Excel® to calculate the "A," "F," and "M" percents of total oxides, but they really need to plot the data by hand to understand how a ternary plot works. For more advanced students than I currently teach, the program IgPet (Carr, 2005) does an excellent job with ternary plots. Concepts of exponential growth (population) and decay (radioactive isotopes) are also difficult to simplify for Excel® or calculator exercises. I do find that the students who have had calculus are often able to solve very advanced problems on calculators, but I plan to develop a complete tutorial on exponents with examples drawn from the subjects which I teach.
At most colleges and universities, we are typically provided with computer operating systems and basic software for text, data, and graphics from Microsoft® and Apple®. If we are fortunate, we may also be able to obtain dedicated software for teaching Earth Science or conducting geological research. For teaching students how to do geology and environmental science using computers and calculators with which most of them are already familiar, I have been very impressed with the software and exercises available from both Texas Instruments® and Vernier®, a company which makes sensors for field and laboratory measurement. The Vernier® sensors output data directly to a TI calculator or a laptop computer, and both Texas Instruments® and Vernier® are also supporting their hardware and software with excellent webpages where students and teachers can share their data and interpretations of results from both field studies and laboratory experiments.

Although sharing data and interpretations are an important and exciting part of scientific research, students also need to be made aware of the difference between sound research use of other scientists' results and plagiarism. As defined for an instructional setting by the Council of Writing Program Administrators (2003), plagiarism occurs "when a writer deliberately uses someone else's language, ideas, or other original (not common-knowledge) material without acknowledging its source." The two important steps for both students and faculty to take in guarding against plagiarism are thus:

1. Determine whether the material to be used in your paper or presentation is common-knowledge within your discipline or is an original idea, wording, illustration, etc... of the author or source that you are reading.
(2) Acknowledge your source using a **citation** with a consistent and accepted style whenever you think that it might not be common knowledge within your discipline.

A "digital" solution to the problem of plagiarism, **Turnitin**, is widely used now in freshman composition classes and as a method of checking student papers in any discipline for plagiarized material. **Turnitin** is completely web-based, and the students submit their papers directly to the program on the internet. **Turnitin** can actually collect the student papers electronically, edit them online by inserting electronic comments into the document, and return them electronically to students. I have tried **Turnitin** out a couple of times, but I am still working out a complete strategy for preventing plagiarism as part of my overall instruction in scientific writing. For courses in which I only assign one final term paper, I typically do not fail a student based purely upon plagiarism but instead require a complete rewrite that shows little or no plagiarism. Papers that misuse a citation style, incorrectly use quotation marks, or fail to include some copied material within their citations are graded down with a warning. These are not actually considered to be plagiarism according to the Council of Writing Program Administrators (2003). In an ideal academic setting, I would assign a series of short writing assignments in which I would expect to see progressive improvement in terms of originality or require a series of drafts if I assign a longer term paper.

Parallel and equally serious problems arise in our digital age regarding the use of visual materials such as maps, dataplots, photographs, and video clips. Draft guidelines for image digitization prepared for the Conference on Fair Use (**CONFU**), for example,
suggest that a "secure electronic network" should always be used to display and provide access to digital images (Lehman, 1996). While it may not be exactly what is intended in these guidelines, a distance learning program such as Blackboard® or Vista WebCT® is secure in the sense that students must log in to the web server using their identification number and password.

Many faculty, myself included, feel that it is actually our job to supplement the image banks provided by textbook publishers with our own visual materials. In my case, many of my materials are my own creative products while others are from published literature and the digital archives of other scientists. I do acknowledge the sources for most images, although my primary objective is to deliver educational content to my students rather than to report on specific scientific findings. With respect to the possible copyright issues, the Society for American Archivists (1997) has actually questioned the need to restrict display to a secure network if the purpose is educational.

Structured internet platforms such as Blackboard® or Vista WebCT® enable the best and the worst of the "distance learning" phenomenon. As documented by Keegan (1990) and others (Maglogiannis and Karpouzis, 2007; Zapalska and Brozik, 2007), distance learning has come about as a result of several social, economic, and educational trends, not all of which are positive from the standpoint of science education. While separation of teacher and learner is never of much benefit to the learner, in reality this occurs throughout higher education given the commitment by most faculty to both teaching and research. In my limited experience in distance education, I have endeavored to maintain discussion, teamwork, and continuous communication with my students using the structured platform just as I have in the past through informal emails and office-
hour sessions. Indeed, these platforms make it quite convenient to set up workgroups and use peer interactions as well as textual and visual materials to reinforce the knowledge students have acquired, motivating them to learn new things together and experience the world more fully.

Students do vary with respect to aptitude and preferences as well as preparation for college-level science instruction. One tool which I have used in the past to help identify student preferences for particular teaching approaches is the VARK (Visual, Auditory, Read/Write, and Kinesthetic) questionnaire developed at Lincoln University (Fleming, 1995; Fleming and Baume, 2006). The questionnaire is short (13 questions) and seems to provide information useful to both student and teacher. As mentioned above, a preference for visual learning and strong visual abilities can be extremely helpful in studying Earth science. Testing students who have trouble with maps and other spatial representations, Ishikawa and Kastens (2005) found a strong contrast between those with high verbal (R) and low spatial (V) preferences versus those with low verbal (R) and high spatial (V) preferences. There also may be an association with gender, since Vandenberg and Kuse (1978) report that women tend to have lower abilities and preferences for spatial or visual learning. These findings are preliminary, and more research on visual tasks specific to Earth science is needed. Results using the GEOSAT test of student ability to comprehend geological structures developed by Kali and Orion (1996) could be directly cross-tabulated against VARK questionnaire results, for example. As a cautionary aside, it must be mentioned that Clark and Feldon (2005) found little if any evidence to support the belief that learning is improved when instruction is specifically designed to accomodate the sort of preferences elicited using the VARK questionnaire.
The range of aptitudes and preferences for individuals in the traditional "college age" population is determined by random genetic variation as well as perhaps by gender. In addition to this more or less random variation, there are some population-specific changes that are occurring as "non-traditional" students are coming to make up more and more of the student body on campus and in distance learning enrollment (Cross, 1981; Knowles, 1970). Aging does diminish certain sensory-motor abilities (eyesight, hearing, reaction time, etc.) but intelligence abilities (decision-making skills, reasoning, vocabulary, etc.) tend to improve. My own experience is consistent with Cross's observation that adult learners prefer a teacher with relevant job experience in the subject being taught who is well organized and yet sensitive to the learning goals of individual students. I think that the "andragogy" concept of Knowles (1970) is a bit overstated, however, in that we are generally teaching mixed classes which sometimes even include high school "joint enrollment" students as well as adult learners and the traditional college-age group. I have taught more than one generation of the same family, for example. Unless one is teaching at a senior center or advising an elder hostel group, the abilities and preferences of the adult learners do not seem so radically different as to overshadow individual and cultural differences.

Cultural differences are rarely mentioned in the science education literature, although it has been observed by Kawachi et al. (2005) that Asian students generally expect teachers to command attention and exert authority. I have noticed lower grades on essays compared to multiple choice tests among some students from Asian countries, but it is hard to determine how much is due to their intellectual traditions and upbringing and how much simply to language difficulties. I know that the understanding of sensory
perception among Buddhists and some other Asian religious traditions is quite different from that of the empiricist philosophers who contributed so much to our basic scientific approach in the English-speaking world. As the Dalai Lama has explained so clearly (Hayward and Varela, 1992, p. 47), contemplative or "yogic" direct perception provides theoretical insight rather than simple sense data.

I sometimes use specific case studies and field examples to attract the interest of particular cultural subgroups within a class of students. Furman and Merritt (2000) went so far as to specifically design one course to attract students from a particular ethnic background who might not otherwise take an Earth science course. They teach a course on African climate in which the enrollment averages 45 percent African-American, of whom over 75 percent are female. Such a proactive approach to course development should hopefully help to reverse both the gender bias and ethnic bias of private and public sector employment in Earth science. A course on Latin America with a strong Earth science component might also be well received at many public universities.

The teaching and learning environment in which we find ourselves today is very different from that in which our fundamental principles of scientific method and critical thinking were first developed. Nonetheless, I do believe that those same principles and values apply in our current digital age, when our classroom may not have four walls and there may be considerable distance between teacher and student. The design of even the introductory Earth science courses has changed, but we still have quite similar learning outcomes in terms of both science fundamentals and a grasp of general concepts. Both student and teacher are ultimately assessed based upon how well students achieve those
outcomes, whether the assessment is in a traditional "blue book" examination or administered in a testing center on a computer.

While challenging, proactive use of educational technology and curriculum design manifests our integrity as we make the systems approach to teaching Earth science work. Our own new experiences as teachers in the digital age will ultimately provide richer experiences of the Earth for our students. Perhaps this was all foreshadowed back in the 5th-century BCE when the philosopher Lao-Tse penned his famous saying:

"If you tell me, I will listen. If you show me, I will see. But if you let me experience, I will learn" (quoted in Ranjan, 1994)
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