Using research to teach the methods of geoscience

Anne E. Egger
Central Washington University

For seven years, I taught at a highly selective, research-intensive institution that attracts very intelligent students. My job at Stanford University included recruiting students into four different undergraduate majors in the School of Earth Sciences, teaching introductory geoscience courses, and running our undergraduate research program. In all of these venues, students told me about their perceptions of the geosciences, and what I learned in that process had a profound effect on how I taught and talked about my discipline.

It will not surprise anyone reading this that few students arrived at Stanford intending to major in the geosciences. My introductory courses were not populated primarily by wide-eyed freshmen seeking a calling, but by seniors in various engineering majors who were fulfilling a natural science requirement. I liked having the engineers in the class: they were smart, had excellent technical writing skills, and didn't put up with anything they saw as busywork. They also chafed under my inquiry-based teaching style, in which I usually let them struggle with data or rock samples or maps, collecting their own data before doing any explaining. I often received comments that were some variation of, "All of this exploration is inefficient. Just tell me what I need to know."

But their presence in my classes gave me the opportunity to point out the different ways that engineers and geologists called on the same concepts and applied them in different ways. I called on the mechanical engineers to tell me how they used stress and strain: to manufacture a material that had low strain under high stress, perhaps. I contrasted that with how geologists use stress and strain: measuring strain to determine the past (or present) stress. The equations and concepts were identical, but the methods with which they were deployed were discipline specific. When I made these connections, I saw many engineers start to nod their heads in class. Ah, I could see them thinking, that makes sense.

Engaging the engineers in class was satisfying, but it was not my only goal. I sought to engage students from a variety of backgrounds in research in the Earth sciences, whether or not they chose to major in it. This meant casting a wide net, explaining what constitutes the Earth sciences, and helping students from majors like computer science, electrical engineering, physics, and history, to name a few, succeed in real research in the Earth sciences.

Casting the net clearly needed to go beyond my introductory courses. Though there were, indeed, a few intrepid freshmen and undecided students who waded into this class, most had already chosen a discipline and were pursuing it. They thought the Earth sciences were a sort of quaint backwater where people actually had to touch real stuff (like rocks) rather than computer keyboards. As a result, I created a 1-unit course aimed at freshmen who just wanted to learn more about what was going on in the Earth sciences at Stanford. A different faculty member visited each week to talk about their research. I worked with them to ensure that they were talking about their research at the level of a student who might be smart but have no background in Earth science. I also asked them to talk explicitly about the methods that they use to do their work. Across the board, without my prompting, they all talked about how they used several methods to develop multiple lines of evidence to support their ideas. A number of students who took this class chose not to major in the Earth sciences but did get involved in research with our faculty, convinced that there were exciting an innovative frontiers here as elsewhere. They either saw how their skills could contribute to Earth sciences research (often the case with computer science majors) or they simply wanted to pursue a topic they were interested in.

Bringing these students from other disciplines into the Earth sciences to conduct research was no small task, however. By casting the wide net, we were catching students who had never taken an introductory geology course or been on a field trip to look at rocks. To accommodate this variability in preparation, I developed a course with a faculty member in Geophysics to introduce these students to research. While much of what we did was broadly applicable to the research process as a whole (reading scientific journal articles, working with your advisor), certain topics focused on the methods of Earth science specifically. How do you develop an hypothesis for a field-based, non-experimental study? What is the goal of developing a model for, say, a volcanic eruption? Why do your peers in other disciplines start writing up their results at the end of the summer when you are just beginning to process your samples?

These experiences working with undergraduate students in research fed back into all of my teaching, at all levels. My classes evolved to include what I consider much more frequent and explicit mentions of what it means to be a geoscientist, the methods that geoscientists use to address questions, and the nature of ongoing research in the geosciences. In my introductory course, I ended every topic by talking about who in the school at Stanford was doing research in that area and the kinds of questions they were still asking. This invariably provoked discussion and occasionally inspired a student to pursue more classes or research. In my more advanced courses, we spent time discussing acceptable levels of uncertainty going back further into geologic time.

In general, in my geosciences classes, I think of myself as narrating what we are doing at every step of the way. That narration might include contrasting the approach a geologist would take with that of an engineer or geophysicist. It definitely includes the methods used, and what other lines of evidence support a given conclusion. It includes actual contributions by actual people, and the questions that those people still have about a particular phenomenon. And importantly for me, it includes the things a student would have to do to get involved in addressing those questions: who to talk to, classes to take, skills to develop.

However, I am also now in a very different setting, teaching classes filled with elementary education majors. Aside from the fact that many of these students are science-phobic, the emphasis in the elementary curriculum (and thus the teacher preparation curriculum) is on experimentation. Despite the differences between these students and (for example) engineering majors, I am able to employ similar tactics to introduce them to the methods of geoscience. My emphasis shifts to highlight alternatives to experimentation for testing ideas and for how it is possible to incorporate those alternatives into an elementary classroom. The association of "experiment" and "science" is very deeply engrained, however, and it can be challenging to overcome not only with these students but with faculty in more classically experimental disciplines that teach these courses.

I suppose that my ultimate goal in narrating the process of geoscience so thoroughly is to find something in there for everyone. The future engineer will be interested in the borehole strain measurements reflecting plate boundary processes; the computer scientist will want to understand how the model of shaking from a magnitude 9 earthquake in Cascadia was built. A future teacher wants to use observations of the world in the elementary classroom as a scientific tool. By explicitly including the methods of geoscience in my teaching, I hope to encourage and foster all of those interests.

Teaching Geoscience Methods in the Field

David Mogk, Dept. of Earth Sciences, Montana State University

Learning in the field has traditionally been one of the fundamental components of the geoscience curriculum. There are many attributes of learning in the field environment that address teaching GeoMethods: definition of learning goals related to mastery of geoscience concepts and content; the development of professional skill sets that are used to describe, characterize, measure, and interpret data acquired directly from natural environments; leveraging the affective, cognitive and metacognitive gains afforded to students through learning in the field; and engagement by students in the community of practice that has been developed and accepted by geoscientists as a result of field studies. An awareness of these attributes will contribute to the design, development and implementation of effective instruction in the field. The following is a summary of a more comprehensive review of learning in the field by Mogk and Goodwin (2012) as part of the Synthesis of Research on Learning in the Geosciences project. Additional insights into teaching and learning in the field can be found in Whitmeyer et al., (2009).

Teaching GeoMethods in a field setting must be done in consideration of many factors. First, learning in the field is meant to encompass a range of activities that are physically conducted in the natural environment: making primary observations of Nature; taking samples; making measurements; directly using the human senses; and indirectly using instrumental sensors to interact with Earth objects and processes. The Earth system is inherently complex, dynamic, heterogeneous, and often chaotic, and presents many challenges to geoscience education. Frodeman (1995) has emphasized the historical and interpretive aspects of geoscience (as opposed to bench top, experimental science mostly done in highly constrained, closed systems). The geologic record is often incomplete or ambiguous, and consequently, the nature of geoscience expertise requires the development of cognitive strategies that allow geoscientists to work effectively in a world in which the available evidence is complex, uncertain, and often missing.

It is also important to consider the scope of field instruction that may range from a two-hour laboratory exercise in a location proximal to the classroom to sustained residential field camps with a duration of weeks to months. Field activities may be immersive or reconnaissance in nature, require geologic mapping on many scales, may focus on sampling activities, perhaps focus on measurements of geologic phenomena (stratigraphic sections, stream gauging), and increasingly use instrumentation (field geophysical surveys) or computer-based technologies ("GeoPads") in the conduct of field work.

Considerations for teaching GeoMethods related to field instruction include:

- Students experience direct contact with the raw materials of Nature in their full complexity, while in the lab, samples are presented without the full context of their natural setting; and, the rational for collecting particular samples may be lost;
- In the field, the scale of observation is large with respect to the observer and thus perception is from an internal spatial viewpoint, whereas in the lab the student

observer is large compared with lab samples;

- Physical movement through the field setting engages all of the senses which are strongly coupled with cognition and access by long term memory for future retrieval and use;
- Field work provides unique perspectives of the world, particularly related to spatial and temporal relations, that cannot be reproduced in laboratory or virtual environments;
- The field setting is a particularly rich environment where students have to make their own informed decisions about what to observe, for what purpose, how to represent these observations and how to interpret and ascribe meaning to their work.
- A trained eye must be developed to know what to look for in complex natural landscapes, as much of the sensory input may be irrelevant to the task at hand; in the lab setting, the objects of study have been selected by someone else and are specifically relevant to the topic of study;
- The field setting has a strong affective component that impacts learning. In some cases, there is a strong motivation to learn based on curiosity, awe and wonder; in other cases there may be significant barriers to learning that derive from fear or uncertainty. The affective domain also extends to interpersonal relations, and strong affiliative ties may develop between students, their peers, and mentors. Managed appropriately, students can gain an enhanced sense of self-confidence and self-reliance.
- The field setting also has a very strong metacognitive component. Field instruction can help students become self-aware of their approach to a given field task, to self-monitor their progress, and self-regulate their actions and make informed decisions as they confront emerging problems, unexpected findings or inconsistencies.

Cognitive, learning and social sciences provide additional insights into the value of field instruction, and why this is so important to teaching GeoMethods:

- The full range of cognitive skills (e.g. Bloom's taxonomy) are engaged in field studies from primary observations and descriptions to higher order thinking sills that emphasize inquiry, discovery, analytical and synthetic reasoning, critical-thinking, and problem solving skills. This also includes the ability to deal with ambiguous, uncertain and incomplete data, and the ability to make internally consistent interpretations (or inferences) based on these data.
- Learning in the field is both integrative and iterative. To be able to interpret natural phenomena, students must be able to bring to bear concepts and knowledge from the breadth of their academic training; in turn, observations in the field may serve to inform students about new tests or lines of reasoning.
- Embodiment—students work in both a natural and a social setting while doing field work. Body and mind are intimately connected and the physical movement through natural environments is critical to cognition and long-term memory. Similarly, field work is often done in field parties, and embodied knowledge is imparted to co-workers through gesture and demonstration. This is an essential component of teaching GeoMethods: demonstrating to novices how to navigate through physical space, and how to interact with the objects of study.
- Inscriptions—are representations of natural phenomena such as maps, graphs, and

other sketches and visualizations that serve to explain, confirm, rationalize and externalize our understanding of Earth. It is the first inscription, where we translate Nature into culture, that is the most important because it is this cognitive step that defines what is important and what is to be excluded in relating outcomes of our studies. There are also "chains of inscriptions" that become increasingly specific in their ability to represent information (but also become increasingly exclusive and removed from the natural state; e.g. geologic map, to cross section, to stereonet, to thin section….). The importance of inscriptions to teaching GeoMethods is that they become permanent, portable, and public records of our understanding of Earth. This is how we "tell the story of Earth".

- Community of practice—The field setting is where students learn FROM Nature and ABOUT science as a social enterprise. The community of practice in the geosciences includes: language translated into practice; the selection and appropriate use of tools to acquire, organize and advance community knowledge; shared ethics and values; and collective understanding of questions, methods, strategies, and their limits and uncertainties. Field instruction also leads to the development of important personal and professional social networks through shared experiences at field camps and field conferences and the norms and expectations of personal and communal conduct.

Some implications that inform how we teach GeoMethods in the field include:

- Field instruction must be student centered, and include emphasis on content and skill mastery, with attention to affective aspects, and intellectually and emotionally challenging at appropriate levels (e.g. Vygotsky's "zone of proximal development").
- Field instruction must be purposeful and well integrated with the rest o the geoscience curriculum. Students must be intellectually well-prepared to optimize learning in the field, and have "fertile minds" that are ready to internalize, organize, prioritize, and utilize the complex relations observed in the field.
- Learning goals for field instruction must be clearly articulated as appropriate to the level of preparation of the students. Learning goals may range from demonstrations of mastery of concepts or skills to a simple appreciation of the wonder of Nature as a possible motivator of learning (and recruitment to the discipline).
- Assessments of learning must be well-aligned with the learning goals. Formative assessments are particularly important, as students may readily get lost (physically and intellectually) in the complexity of the natural environment.
- Practical aspects of teaching GeoMethods include the need for careful planning by the instructors to insure a good and productive field experience. And recognize that going out into the field does not necessarily mean that students will learn.

Finally, I'd like to emphasize that learning in the field affords types of learning that cannot be achieved as easily or at all in other more controlled learning environments. The field setting evokes a very strong affective response that is strongly connected to cognitive functions. The learning of science is best done in the doing of science, and this is well-realized in the embodied practice of field work in both natural and social settings, and through the creation of inscriptions to represent natural phenomena. I would affirm that learning in the field is an essential component of professional training for ALL geoscientists, regardless of the sub-discipline of interest. It is in the field setting that the full history of Earth, its processes and products, over a range of temporal and spatial scales, are fully realized. It takes a long apprenticeship for novice geoscientists to be fully inculcated into the community of practice, so my advice is to get out into Nature early and often.

REFERENCES

Frodeman R., 1995, Geological reasoning: geology as an interpretive and historical science: Geological Society of America Bulletin, v. 107, no. 8, p. 960-968.

Mogk, D. W., and Goodwin, C., 2012, Learning in the Field: Synthesis of Research on Thinking & Learning in the Geosciences, in K. Kastens and C. Manduca (eds.), Earth & Mind II: A Synthesis of Research on Thinking & Learning in the Geosciences, Geol. Soc. Amer. Sp. Paper 486.

Whitmeyer, S., Mogk, D., and Pyle (eds.), 2009, Field Geology Education: Historical Perspectives and Modern Approaches, Geol. Soc. Amer. Sp. Paper 461.

David Mogk, Dept. of Earth Sciences, Montana State University

[link http://serc.carleton.edu/NAGTWorkshops/coursedesign/goalsdb/12058.html 'Mineralogy'] is often the "gateway" course to the geoscience major. As such, it plays an important role in the geoscience curriculum by setting professional standards and expectations in the training of young geoscientists. The [file 6175 'learning outcomes'] of my Mineralogy course are closely aligned with the methods that geoscientists use in their professional careers: I do expect my students to master a certain amount of scientific content related to minerals, their composition and structure, the context of minerals in interpreting geologic setting, processes and history, the centrality of mineralogic principles in addressing geoscience research questions and applications to society. But in addition, a major learning outcome of my Mineralogy class is the [link http://serc.carleton.edu/NAGTWorkshops/earlycareer/research/habitsofmind.html 'scientific habits of the mind'] that help to prepare students for a career in geoscience. Beyond content knowledge, my goal is to help students: a) develop technical skills (e.g. mineral identification, use of the petrographic microscope, XRD), b) develop related transferable skills (e.g. communication, quantitative, and interpersonal), c) make connections between our Science, and their personal professional goals, or with societal issues by engaging aspects of the affective domain such as curiosity and motivations to learn; and d) gain exposure to geologic "ways of knowing" so that they can be reflective (metacognitive) of not only what we know, but also how we know and to be able to formulate strategies to learn in new domains of knowledge. The students' learning outcomes in my course are focused on mastery of geologic content, skills, and ways of knowing; my personal course outcomes are students who are prepared to be contributing Scientists.

The design of my mineralogy course uses a historical approach that emulates the evolution and advances of the science over the past 300 years or more. This is a kind of disciplinary "ontology recapitulates phylogeny": the stages of development of Mineralogy as a science, must be reproduced by the students so that they can understand the underlying reasoning and full context of what is known and how we have come to this state of current understanding. (And I would posit that this is true also for other disciplines in the geosciences and beyond). A history of mineralogy has been written by Hazen (1984; and this is required reading by my students). Initially, Mineralogy was largely a descriptive science until the mid 1800's, with two camps of practitioners who advocated use of physical properties of minerals (e.g. Mohs, Wegner) v. crystallographic characterization (e.g. Steno, 1600's) as the basis for mineral identification. In both cases, description was the primary geoscience method. (And consequently, the science of Mineralogy has labored under a general perception that it is predominantly a descriptive science, that looks for increasingly arcane and rare specimens, and should be relegated to museum status along with its samples). James Dwight Dana was able to integrate these into the coherent classification scheme that is universally used today. This answered the primary question of **"what"** minerals are.

The more interesting question of "**why**" do minerals exhibit their unique compositional and physical properties could not be addressed until the advent of atomic theory (e.g. the Bohr model of the atom) and an understanding of the nature of chemical bonds (Linus Pauling, 1954 Nobel Prize for Chemistry). These theoretical considerations led to deeper explorations of crystallography, crystal chemistry, and crystal structures. An understanding of the relative strength and direction of chemical bonds provided the basis for explanations of the physical properties of minerals such as cleavage, hardness, melting point and ductility.

But "**how**" do we know, what is the evidence? Technology is really the answer, that allow for **precise and reproducible measurements of natural phenomena**. Carangeot applied a contact goniometer (mid 18th century) to confirm Steno's "law of constancy of interfacial angles", and Wollaston developed the reflecting goniometer (mid 18th Century). At about the same time, Cronstedt and colleagues used blow pipe methods to do rudimentary chemical analyses (which by the way led to discovery of 84 elements of the Periodic Table first described as a major or trace component of minerals). A huge leap in technology was realized in the application of the petrographic microscope to the identification of minerals and analysis of textures in rocks (Nicols and Sorby, mid 19th Century). It was really the discovery of X-rays and their application to determination of crystal structures (that resulted in the award of the 1915 Nobel Prize in Physics to the father-son Bragg team) that opened up a revolution in analysis of the structure and composition of minerals. This confirmed the supposition that there were indeed atomic scale building blocks (unit cells; first proposed by Steno) that were organized in definite proportions and with ordered atomic arrangements that we recognize as minerals. The atomic scale ordering is reflected in the mesoscopic crystal forms we can hold in our hand. After X-ray diffraction, other technologies emerged in the 20th century to further characterize the morphology, composition (elemental, isotopic), structure, and other physical properties of minerals: scanning electron microscopy, electron probe microanalyzer, mass spectrometry, Mossbauer spectroscopy, and recently atomic force microscopies. These are the tools that allow us to **test** materials, and the theories that control their properties and occurrences.

Finally, "**who**" should care about mineralogic research? Geoscientists, colleagues in other science and technology disciplines (chemistry, physics, biology, engineering), and citizens. Minerals are the monitors of geologic process and history: the story of Earth is recorded in the composition, structure, and natural associations and occurrences of minerals in the Earth system. Minerals are the result of natural experiments conducted over geologic time, and as a result often reveal fundamental principles about how the universe works. And, minerals have been used since the dawn of civilization to support the material needs of society.

So, the evolution of the science of mineralogy includes the early description of minerals, theory that explains their properties, experimental and analytical methods that tests and confirms our theoretical understanding, and ultimately, this information becomes relevant and useful to the progress of society and to sustain human society. Enough of my homage to Mineralogy.

So how does this apply to Teaching GeoMethods?

In the first half of my Mineralogy course, the focus is on determinative mineralogy and hand sample identification. But as L.C. Graton famously stated: "*The purpose of classification is not to enunciate certain and final truths, but rather, to be used as stepping stones towards greater understanding.*" This early training is really an exercise in guided **observation** and **description**:

- Helping the students know what to look for amidst the complex variations encountered in natural samples (e.g. recognizing multiple varieties of quartz; knowing to avoid alteration).
- Prioritizing evidence (what properties are diagnostic, what is permissible or exclusive)?
- Measurements (aspect ratio, interfacial or cleavage angles);
- The beginnings of synthetic and analytical reasoning (using multiple lines of evidence to formulate an internally consistent interpretation; interpreting mineral occurrences in the context of larger geologic settings); and
- Clarity and precision of descriptions and appropriate use of scientific terminology as an essential component of communicating scientific knowledge.

A basic knowledge of mesoscopic properties of minerals provides the foundation for investigations of the more abstract, **theoretical considerations** of crystallography, crystal chemistry, structure. Geomethods used in these instructional units include:

- Spatial reasoning, particularly with respect to the 3-dimensional atomic "architecture" of mineral structures (e.g. "I-beam" chains of Si-tetrahedra in pyroxenes and amphiboles; stacked sheets of micas);
- Quantitative reasoning in crystallography (set theory as the basis of point groups; Miller indices as vector representations; trigonometric relations);
- Modeling: physical, analog models are used to represent mineral structures (ball-and-stick models); computer-based visualization models are used for dynamic demonstrations of crystal structures.

Analysis of mineral properties requires **analytical thinking**. Students must understand fundamental principles of the analytical technique, procedures related to sample selection, sample preparation, instrumental parameters, standardization, data acquisition, replication, data reduction, and data representation. Students need to be trained to be "critical producers and consumers of data". These principles are applicable to instruction and use of techniques such as optical mineralogy, X-ray diffraction, SEM/EDS techniques; all of which are easily accessible in an introductory Mineralogy class.

A final, in-class research project is designed to pair Mineralogy students with faculty or graduate student mentors. Each mentor provides materials to be analyzed to address a mineralogic question related to their own research. Topics explored have ranged from composition of dinosaur bones and eggs to salts related to saline seep occurrences, composition of fault gouge, clay mineralogy in off-shore turbidites, ore mineralogy of a poly-phase precious mineral deposit….Students must write a short research proposal with methods that will be used to characterize their specific Earth materials. They then conduct appropriate experiments to characterize morphology, texture, composition and structure of their materials. This is a first critical exposure **to integrative problem-solving** (using multiple independent lines of evidence to solve a mineralogic problem).

So, in summary, students in a mineralogy course can develop through the same stages of discovery that the discipline of Mineralogy followed over almost three centuries: 1) an early emphasis on description of mesoscopic physical properties that led to a universally accepted classification scheme; 2) codification of the principles and theory of crystallography and crystal chemistry that explains and confirms the reasons for the expression of these physical properties; 3) technology-assisted analysis of materials (petrographic microscope, XRD, SEM/EDS) to test hypotheses about their occurrences and properties; and 4) applications to questions of Scientific or societal consequence, using problem-solving strategies that integrate multiple lines of evidence.

A final note, this historical approach to teaching mineralogy not only introduces a scaffolded sequence of geomethods used by practicing geoscientists, but also ascribes to the tenets of successful teaching in the sciences as articulated in Science for All Americans (AAAS, 1989): Start with questions about Nature, and Work from the concrete to the abstract.

AAAS, 1989, Project 2061, Science for All Americans, AAAS: Washington DC.

Robert M. Hazen **1984,** Mineralogy: A Historical Review, Journal of Geological Education v 32, p288-298.

My Personal Journey into the Methods of Geoscience

Jennifer L. B. Anderson
Geoscience, Winona State University

It has been so interesting to plan for this workshop because over the last year I've really started reflecting on how the methods of geoscience differ from the other more "traditional" sciences. Perhaps the methods I use are too ingrained and I have never tried to tease them out and clearly identify them before. Perhaps it is because I started as a physicist and so I am familiar with the "scientific method" as it is "supposed" to be. Perhaps it is because my primary method used for my PhD is experimentation and so I didn't veer so far from the "traditional scientific methods." Preparing for this workshop has given me the opportunity to reflect on my own journey. It has been interesting to realize how I struggled with the "methods of geoscience" as a student and professor myself. Even more interesting will be how I decide to reflect my journey and my new understanding in my courses.

I started my college life as an astrophysics/physics major where I loved lectures filled with equations and tidy problem sets. As a sophomore, I realized that my passion in astrophysics was really for the planets and so I was pointed toward the Geology and Geophysics department. I took my first introductory geology course and was completely hooked. And so I became a geophysics major.

I remember sitting in my first geology-major course and listening to the professor. She was talking about really interesting things as she leaned against the front table. I thought – "Wow! This is so neat! I wonder when she will start to lecture?" And then I looked around at my classmates who were scribbling furiously as she spoke and I realized that geologists didn't write equations on the board, that I would have to learn from "stories" and the spoken word (not to belittle the field – I believe that my principal job as a geologist is to "tell stories about the Earth"). I bought a geology dictionary to help me with the vocabulary I needed in this new field. Indeed, I felt lost many times that first semester, as though I had entered a foreign country where I didn't speak the language or know the customs. This was my first indication that geology was different than my physics and math courses, my introduction to the "methods of geoscience." Today I can look back and realize that I was not prepared by any of my K-12 or physics background to recognize the science methods behind geology. I didn't even know how to take notes!

But my fascination with geoscience topics pulled me through this first difficult semester and I became indoctrinated into the methods of geoscience through my courses, professors, fellow students, field work, and research projects. I went to graduate school to become a planetary geologist and specialized in experimental impact cratering. While I still used the "typical" methods of experimentation, mathematical models, and data analysis, I was also learning how to interpret planetary surfaces from orbit, how to use what we know of the Earth to inform our understanding of other bodies in our solar system, and how to "do science" and "figure stuff out" from millions of miles of away. Again, looking back at it, I feel that I was quietly indoctrinated and that the new methods were never explicitly explained or defended.

After graduation, I took a position in a small Geoscience department at Winona State University, a primarily undergraduate institution. The Geoscience department and its classes were very field-based and then in I walk – an experimental planetary geologist. While I had excellent field courses and experiences in both college and graduate school, I did not have direct research experience in the field and so I again experienced some of the differences inherent in the methods of geoscience. But this time, I was trying to convince Geology majors that experiments (and mathematics) were applicable to geoscience research. The majority of geoscience undergraduates at all levels, in my experience, primarily want to go outside and do field work. I had already noticed that geoscience was considered somewhat of a "less scientific" field by other scientists and the general public. Suddenly I was dealing with science majors who did not want to "do math," who seemed confused by a geoscientist who principally did experiments. In the other direction, I have been working hard to adapt my research to be more field-oriented and so I found myself again learning about the methods of geoscience as I work with my students and colleagues in the field to interpret local impact-crater related deposits.

Finally, I also work with pre-service elementary education majors, teaching in their inquiry-based, interdisciplinary science content courses. As a geophysicist, I teach in both courses physics/chemistry and Earth/life science. Over the past year I have been thinking more and more about the differences between the methods of science. In these science content courses, we talk extensively about how experiments are done in the physics & chemistry course. But we don't cover the methods of geoscience in the second semester Earth & life science course. Upon reflection, it is obvious to me that we need to be more explicit in our discussions of this in both classes (also because I think that biologists share some of our methods).

I currently feel at a cross-road in how I teach the methods of geoscience in many of my classes. I look forward to learning more from all of the participants at this workshop about the methods of geoscience and how I can help my students experience and understand these methods more fully. As I have reflected upon my own journey into geoscience, I will be able to share my experiences with my students as I help them to become familiar with these methods. I think that the content of this workshop will affect most of my courses. I will bring back these ideas to my Geoscience colleagues and my colleagues in the Science Education courses. I look forward to helping illuminate the methods of geoscience with general-education students, geoscience majors, Earth science teaching majors, and elementary education majors.

The use of field experience and anecdotes in teaching

Joel S Aquino, PhD, STEM, Gainesville State College

"Teaching geology without a fieldtrip is blasphemy"
Joel S. Aquino

My experience in teaching the methods of geoscience or science in general comes from my 30 years of combined mineral/exploration industry, research, tertiary and 9-12 public education background. This experience has been fortified by global travels in Asia, Europe, Australia and North America and had been recognized for being a part of a team that discovered a $13 billion dollar Cu-Au mine in Laos and several teaching awards. As a full-time high school science teacher, I am also trained in differentiated, gifted and ESOL instructions. Thus, my pedagogical skills transgress across real-world application, multi-disciplinary fields, cross-cultural borders and 9-16 education. In particular, my combined HS and college teaching backgrounds give me a complete spectrum of the learners' profile and related adaptable teaching strategies.

As a part-time college instructor, I handle the evening classes (Physical or Historical Geology) where majority of the students graduated more than 5 years ago and have day time jobs. Most of the time, the students who take these courses are non-science majors whose math skills are generally limited to algebra. Thus, it is a challenge for me on how to make the course engaging to the students without losing its integrity. Here is where my mining/ exploration industry experience becomes helpful.

My decade stint as an exploration geologist gave me a wonderful opportunity to practice my major in economic/resource geology where I was involved in different stages of exploration from grassroots activities to bankable feasibility studies. Each stage involves different critical thinking skills from detailed field observations, conceptual modeling, drill testing, metallurgical characterization and recovery, mining strategies, resource calculation and modeling, environmental impact assessment, and economic analysis. Equally important is the non-technical side of field management such as personnel, community, government and media relations. An added challenge is the transition from a geologically-driven project to an engineering-driven project where the role of a geologist drastically shifts from a project leader to a consulting support role.

This industry experience heavily influences the way I run my geology courses that focuses on exploratory labs first and a follow-up summary lecture later. These labs are focused on fundamental physics and chemistry concepts and its real world application in geosciences. This way, I emphasize more on the PROCESS OF SCIENTIFIC INVESTIGATION rather than the numerous geological terminologies that students barely remember after taking the course. A process-oriented lab is an enriching discovery experience for students that can be carried on in many other fields. I have created several labs that mimic each stage of exploration and can be a full-guided inquiry to a design lab that only involves a prompt question. These labs are inexpensive (< $5/group), manipulative and conceptual that can be differentiated up to the middle-school level. Each lab requires a written report that focuses on the 6 levels of Bloom's Taxonomy of Learning and improving their writing skills. The lower levels of knowledge, comprehension and application are used as a rubric for discussion of objectives, summary of literature review, methodology and data processing/ presentation (table, graphs, photos/ sketches). Meanwhile, the higher levels of analysis, synthesis and evaluation are used in the sections of analysis/conclusion (pattern recognition, cross-correlation and implications with underlying geologic process and literature readings), evaluation of weaknesses and practical suggestions for improvement. Non-technical aspects of the lab report that are also assessed include group dynamics (inter-personal skills), punctuality and manipulative skills (use of instruments and lab safety procedures).

As an off-shoot of my industry experience and global travels, my lectures are also reinforced, if not, interrupted by my field anecdotes and slide collections. I notice that students prefer this "personal" touch as the class will either burst with laughter or looks aghast with the differences in cultural perspectives of one nation to another.

In summary, I teach my introductory geology classes with the necessary scientific concepts and skills that they will carry not only in the understanding of the earth's processes but also applicable to other disciplines. Connecting these lessons to real-world experience gives it more meaning and incorporating design labs give the students a sense of ownership.

Supporting Attachments

The child as history: recapitulation goes to school

Kip Ault, Teacher Education, Lewis and Clark College

As an essay to share with the participants of the "Teaching the Methods of Geoscience" I have chosen "The Child as History." The essay is based upon lectures from a course I taught to prospective science teachers for several years, "Curriculum & Inquiry," a course anchored in the philosophy of John Dewey and the writings of Joseph Schwab (perhaps "the father" of modern inquiry-style science teaching). The geoscience community may find the influence of evolutionary and paleontological thinking on educational theorizing to be both interesting and surprising. "Cultural Epochs" in effect are analogs to geologic time periods punctuated by progress in the fossil record. This theoretical construct of pedagogy leads directly to Dewey and Piaget, whose influences remain consequential. These 3 pages are an excerpt from a longer essay which I would be more than happy to share upon request.

The Child as History: Recapitulation Goes to School

Ernst von Haeckel's recapitulationist metaphor—the idea that stages in the development of an individual mirror its evolutionary past—has anchored theories across many fields. Education is no exception. At the end of the nineteenth century and during the dawn of the twentieth, the influential American educator G. Stanley Hall's approach to child development assumed recapitulation. For example, he interpreted childhood fears as descended from "the problems of ancestral adults, not the environments of modern children." (Gould, 1977, p. 140) Whether learning to walk, experiencing fear, progressing in play, or becoming socially adept, children progressed through stages that mirrored the history not only of their biological species (from motions evocative of swimming fish, through crawling cat-like, to upright posture) but also of their race, from savage to civilized, and nation, from classical to modern.

For Hall, schooling needed to match the child's recapitulation journey and refrain from suppressing expressions essential to completing proper development at each stage. Hence, even savagery ought to be accommodated through opportunities afforded by the natural world—hunting, for example. If not, arrested development would presumably cause problems later in adulthood.

By trusting the instincts of the young child at play in the natural world as a form of early education, Hall mirrored Jean-Jacques Rousseau's principles. In effect, Hall and his followers provided the eighteenth century Enlightenment philosophy of Rousseau with a nineteenth century scientific foundation. The root metaphor making this elaboration appear both sensible and compelling was "nature." Rousseau's writings extolled the natural and vilified corrupting influences imposed upon young minds. He advised in reference to the early education of Emile, "Leave nature to act for a long time before you get involved with acting in its place, lest you impede its operations" (Rousseau [1762] 1979, 107). Hall found in biology a rationale for the idealistic trust in nature articulated by Rousseau. There was, it seemed, a basis in scientific truth for Rousseau's rhetoric. Hall fashioned himself as "The Darwin of the mind" (Hall, 1923, 360; cited in Kliebard 1986, 35).

Though unable to fully organize schooling in a fashion that might delight Huck Finn (including a stage of freedom intended to promote the development of the noble savage), near the end of the nineteenth century leading educators did try to organize curriculum for children as a progression through the epochs of past cultures. They reasoned, "If all the world is in upward flux along a single path of development, then instruction must follow nature as a child mounts through the stages of lower creatures and primitive civilizations towards a higher humanity" (Gould 1977, 148).

As described by Gould, leading American educators made pilgrimages to German universities during the 1870s and 1880s to learn the theory of culture-epochs, Kulturhistorischenstufen. Upon their return, they disseminated these views as anchors to an emerging progressive philosophy in American schools. Soon afterward there emerged the Child Study movement, which faulted schools for excessive drill, rote learning, and curriculum poorly matched to the developing needs of children.

The child-centered, Herbartian prelude and postlude to culture-epochs theory

American educators also learned in Germany the educational philosophy of Johann Friedrich Herbart (b. 1776; d. 1841) and in 1892 formed, in opposition to the traditional curriculum of classical humanism, the National Herbart Society. Its members thought of themselves "as scientific in outlook" (Kliebard 1986, 18). Well into the twentieth century Herbart received credit for his "pedagogics . . . still the source of much of our best educational theory and practice" (De Garmo 1953, 115). The National Herbart Society lived for not much more than a decade, but it galvanized reformers such as Hall and brought John Dewey into the educational fold. The National Herbart Society was Dewey's cradle.

Herbart criticized Hegel's approach to resolving contradiction through synthesis. For Hegel, synthesis meant establishment of a level of thought superordinate to the contradictory notions (thesis and antithesis). De Garmo cited the prime example of Hegel's method: there can be "being" and "non-being," its opposite. The higher level synthesis brings these two opposites together. In this case, the synthesis is "becoming" which implies movement from non-being to being.

Herbart, according to De Garmo, taught the acceptance of the contradiction of opposites and instead of resolving such tension through synthesis at a higher level advised his followers to "honestly endeavor to remove the contradictions inherent in our everyday thought of the world" (De Garmo 1953, 115). In order to remove contradictions, Herbart would accept "any presupposition, rational or irrational, which promises to resolve the difficulty, even though the principle of explanation should forever resist demonstration as to its reality" (De Garmo 1953 115).

There is no clearer expression of this approach in the present than the "principle of charity" introduced to the science education literature by Klaassen and Lijnse (1996). Klaassen and Lijnse analyzed a classroom dialogue in which a student resisted the teacher's explanation of force. The teacher used the term "force" consistent with Newtonian laws of motion. The student, however, rejected the statement that a table exerted a force on a resting object. The exasperated teacher was unable to convince the student that she held a misconception and to replace it with the Newtonian concept.

Klaassen and Lijnse analyzed the teacher-student quarrel and concluded that the participants did not, in fact, differ in belief or opinion "about how things are in the world" (129). They quarreled because they were "not aware that they do not assign the same meaning to the expression 'to exert of [sic] force'" (129). Klaassen and Lijnse endeavored to determine the student's meaning of "force" from her use of the term. They summarized their method as follows:

Assign such meanings to a speaker's expressions that she comes out as consistent and a believer of truths. (Klaassen and Lijnse 1996, 129)

Klaassen and Lijnse attributed their principle of charity to the influence of Davidson's philosophical work (1984). Its antecedents, however, are clearly in the Herbartian agenda to remove contradictions in everyday thought about the world by accepting a presupposition that removes the contradiction. What Klaassen and Lijnse, after Davidson, have done is to apply this principle to the problem of communication about the everyday world. In so doing, they have arrived at a conclusion that is very respectful of student intelligence. In addition, they have responded to Rousseau's admonition not to ascribe adult meaning to children's words:

They have another meaning than ours without being able to perceive it; so that, appearing to answer us quite exactly, they speak to us without understanding us and without our understanding them. It is ordinarily due to such equivocations that we are sometimes surprised by their remarks. (Rousseau, 1762/1979, p. 73)

Modern educators would refer to children's surprising equivocations as "misconceptions." The principle of charity, however, makes a less summary judgment. Of salience is the attention to meaning from the perspective of the child and the attempt to align the curriculum in order to capitalize on natural interests. At the same time there is an implicit need to make curriculum respond to and encourage the natural development of the child.

Child-centered, Herbartian reformers endorsed culture-epochs theory because "a curriculum organized in this way had a guaranteed appeal to children's interests. Children, they felt, had a natural affinity for materials drawn from a historical epoch which corresponded to their stage of individual development" (Kliebard 1986, 46). The development of thought flourished best, believed the Herbartians, in the context of children pursuing their natural interests. Culture-epochs theory, in effect, attempted to rest the task of authoring school curricula on a firm, scientific foundation, one that would validate the romantic appeal of promoting children's natural interests.

The Herbartians also emphasized the principle of "apperception." Apperception is "the mental assimilation that takes place when we use knowledge already acquired to interpret new knowledge" (De Garmo 1953, 116). This principle figures prominently in Ausubel's psychology and theory of meaningful verbal learning. Ausubel is frequently quoted as saying, "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel 1968, vi; cited in Novak 1977, 24). Ausubelian learning theory led to the practice of "concept mapping" as a tool for representing the network of concepts comprising a student's prior knowledge.

Finally, and most importantly, Herbartians stressed "direct interest" and the derivation of interest from experience. Interest stemmed from empirical, causal, and aesthetic aspects of the subject and from sympathetic and social dimensions of interaction with others. For the Herbartians, interest had both subject and social components. At the pinnacle of Herbartian method stands "the well-ordered activity of the pupil in the solution of problems and tasks" (De Garmo 1953, 117). These are problems and tasks of direct interest to the pupil; culture-epochs theory suggested what they should be. However, Herbartian philosophy predated culture-epochs theory and as modified by John Dewey extended far beyond it. Herbartian philosophy has promoted social interaction, experiential learning, interest-centered curriculum, and subject integration.

References

Ausubel, David P. 1963. The Psychology of Meaningful Verbal Learning. New York: Grune and Stratton; cited in Novak, 1977, 24.

Davidson, D. 1984. Inquiries into truth and interpretation. Oxford: Clarendon Press; cited in Klaassen and Lijnse, 129.

De Garmo, Charles. 1953. Herbart, Johann Friedrich. In Encyclopedia Americana, vol. xiv. New York: Americana.

Gould, Stephen Jay. 1977. Ontogeny and Phylogeny. Cambridge: Harvard University Press, Belknap Press.

Hall, G. Stanley. 1923. Life and Confessions of a Psychologist. New York: D. Appleton; cited in Kliebard, 46.

Klassen, C.W.J.M. and P.L. Lijnse. 1996. Interpreting Students' and Teachers' Discourse in Science Classes: An Underestimated Problem? Journal of Research in Science Teaching 33, no. 2: 115-134.

Kliebard, Herbert. M. 1986. The Struggle for the American Curriculum 1893-1958. Boston, Mass.: Routledge & Kegan Paul.

Novak, Joseph D. 1977. A Theory of Education. Ithaca, N.Y.: Cornell University Press.

Rousseau, Jean-Jacques. [1762] 1979. Émile or On Education. Translated by Allan Bloom. New York: Basic Books.

Supporting Attachments

The Child as History (Microsoft Word 2007 (.docx) 22kB May4 12)
The Molluscan Child: From Recapitulation to Piaget (Microsoft Word 133kB May4 12)

Search the Site Go

Teaching the scientific method at a community college

Pier Bartow, Natural Resource Systems, Klamath Community College

About 4 years ago our science department at Klamath Community College (KCC) decided to standardize the way we presented the Scientific Method to our students. The way this all came about was that we realized that every textbook in every science course we offered had different steps, or at least a different number of steps to the Scientific Method. If they were taking two or more science courses in a quarter they would have to remember more than one way to interpret the Scientific Method. Some textbooks had as few as three steps while others had many more: The age old debate between the clumpers and the splitters. So after long thought, hard work, and many revisions, we came up with a compilation of steps, found in numerous books in various disciplines within our department. We came together and debated the merits of both sides of the issue, and being a very egalitarian group decided we were all right. The result being, "The insert here Steps of the Scientific Method". At this point the head of our department made the final cut to 6 steps. Not too many, nor too few, but just right. The steps being:

1. Observation
2. Question
3. Hypothesis
4. Test/Experiment
5. Results
6. Conclusion

Now, this may seem a whole lot about nothing to you, dear reader. But, this allows a certain continuity, especially in sequential courses like Physical Geology 1 and 2. A student having taken one science course here will be better prepared, and hopefully have their understanding of the Scientific Method reinforced. The very first Lab in all of my courses is on this subject. We also include, "The Parts of a Lab Report"; "Independent Investigation Guidelines"; as well as a fill in the bubble flow chart and quiz. (See Attachments) They also get to make up their own experimental Procedure. Which they seem to have fun designing, knowing they will not have to actually perform the experiment. They can get pretty wild!

For some students this is the first time they learn that scientist think differently than the rest of the world. I talk to them about the Ancient Greeks, and how they were the first to begin the systematic study of natural phenomena. I describe some of the achievements of these great thinkers. I also name a few, with the belief that credit should be given, where credit is due. I warn you though, mentioning more than two or three Greek names tends to make their eyes glaze over. We talk about the difference in the use of the term theory in everyday use, verses what it means in a scientific context. I will use an example such as, "I have a theory that that darn dog next door got into the trash can last night!", being a completely different use of the word than "The Theory of Evolution".

I will bring-up Scientific Method throughout the course to talk about bias, inaccuracy, and conflict. In a Geology Lab presentation I point out that Wegener's idea on Continental Drift was a hypothesis not a Theory. The reason being that he did not have a mechanism to explain his findings. Then I ask them if Plate Tectonics is a hypothesis or a Theory. The aim is to get them to debate and then conclude that a Theory must have a preponderance of evidence and the findings must be repeatable under many different conditions and circumstances throughout the world. We then can look at plate boundaries as surface morphologies that reflect convection currents in the Asthenosphere.

The main reason we have taken this approach is it gives the student a starting point for them to begin to think as scientists. This approach to the Scientific Method also gives them a sense of continuity here at KCC. They learn it once and in every science class they take it is reinforced. I'd like to think this is a good thing that will encourage them to continue with their studies in the Sciences.

Supporting Attachments

Teaching the Scientific Method at Klamath Community College (Microsoft Word 2007 (.docx) 17kB May7 12)
The Six Steps of Scientific Method (Acrobat (PDF) 611kB May7 12)
Scientific Method Part 2 (Acrobat (PDF) 798kB May7 12)

Geoscience Fundamentals: Teaching the Methods and Philosophies of Science through Writing

Barbara Bekken

I am suspicious of faculty who, when they begin to converse on curricular planning, open with, "When I was a student…" but this time, it was I who was speaking, and I continued with, "I wish I had been taught how to think like a scientist." When I graduated with my bachelor's degree, I had a firm grounding in both didactic and procedural knowledge in the geosciences. I knew the 'whats' and the 'how-tos' of geology; I could identify rocks, map like a fiend, and reason my way through a phase diagram, but I did not really know how to think like a geoscientist, and I also didn't know how to write like one either, even though I had written an average of four papers each term for several years. (I recently cleaned out my office and found all of my term papers.) Thus, my weaknesses in writing were not for lack of opportunity to write. Instead, they were for lack of *explicit* opportunity to think about how to think about science and then to think about how to write about my thinking.

As faculty, we are guilty of assuming that our students have developed far more sophisticated knowledge structures than they actually have. And when we misjudge their ability to connect information with concepts, they are disadvantaged. But with more explicit training in the methods, philosophies, historical underpinnings, and communication forums of the geosciences, undergraduates can develop more robust ways of thinking about and working to solve geologic problems. However, in order to develop more sophisticated scientific habits of mind, the methods of science need to be made explicit across an entire program such that students can shift from naïve and disconnected knowledge structures to more connected and apprentice-like ways of thinking about, reasoning through, and doing science.

As I look back on my educational experience, I did not realize that my philosophical naiveté was an issue until I entered graduate school, but as I did so, I found myself negotiating the widest intellectual chasm I had yet faced. Between undergraduate and graduate school, the rules about schooling change. Beginning graduate students are tossed up a few rungs on the ladder of Bloom's taxonomy with virtually no explicit training in professional-level scientific reasoning, information literacy, authentic problem solving and the importance of writing in clarifying these important learning and research skills. Graduate students are expected to think and communicate like geoscientists, but many have yet to develop these skills. To say that my first year of graduate school was painful is an understatement. And while I do not believe that all beginning graduate students share my experience, 25 years in the faculty trenches has convinced me that many first-year graduate students experience similar and variably prolonged intellectual panic attacks. Thus, to better prepare VT undergraduate geoscience students for graduate school or their first geo-career, I chose to design and teach a geoscience course that explicitly addresses the philosophical, methodological, historical, and communication void that is present in many traditional undergraduate programs. Beginning in 2001, Virginia Tech added "Geoscience Fundamentals" as a required core course for all undergraduate geoscience majors. This essay describes the curriculum and pedagogy of Geoscience Fundamentals, how it has evolved since 2001, and where it is going post-2012.

Geoscience Fundamentals (Fundamentals) is the professional entry point to the geosciences degree wherein majors are introduced to: 1) thinking like a geoscientist by using the methods and philosophies of science in an authentic earth-related project; 2) reading, writing, speaking, and portraying geoscientific concepts using forums of communication common to the profession; and 3) developing a career vision and a professional persona through electronic media. Development toward these outcomes is essential to support the use and integration of content and procedural information offered in subsequent geosciences core coursework, many of which will require that students maintain and update progress toward their degrees by continually updating their electronic portfolios with both formal communication products and other career envisioning and planning materials. The required sub-disciplinary courses that make up the core of the program culminate in a capstone integrative research and communication experience, the Senior Seminar, which gives students an explicit opportunity to revisit and hone philosophical, methodological and communication skills introduced in Fundamentals and used in the sub-disciplinary courses.

Currently, Fundamentals is a three-credit course intended for sophomores and transfer students who have completed one year of introductory geoscience coursework (in essence, physical, historical, and a field observations course). Once students have whet their content appetite for the geosciences, Fundamentals introduces them to how geoscientists think, reason, and act. But Fundamentals did not start out this way. Beginning in 2001, it was offered as a 1-credit, first-year experience course for beginning geoscience students. But students vote with their feet and that was not the population the course actually served. Instead, Fundamentals was populated with students from first through fourth year; many of whom were transfers who had completed at least one and perhaps more geoscience courses. I soon recognized that this range in preparation made the course too challenging for first-year students who were not yet grounded in the kinds of problems that geoscientists study. This recognition necessitated adding pre-requisites in 2003, which moved the course entry point to the sophomore year. By doing so, Fundamentals served as an introduction to the ways of thinking and writing about geoscientific problems once students had some idea of what constituted a geoscientific problem.

In 2007, VTs Department of Geosciences agreed upon and adopted five learning outcomes for the Bachelor's program in geosciences. Fundamentals supports two of the five departmental learning outcomes:

- Use conventions for communication and information-searching common to the geosciences to: 1) search for and evaluate geoscientific and related information, 2) write a geoscientific proposal and report, 3) write a geoscientific abstract and give a companion oral presentation, and 4) design a geoscientific poster.
- Propose a means for studying a typical geoscientific problem; select and apply appropriate scientific methods and tools to generate data, analyze and interpret those data, and describe findings according to the conventions appropriate to the problem.

Assessment of students' performance on independent research project design, development, action, and communication indicates a marked improvement of approximately one letter grade over the decade in which Fundamentals has been offered. Most of this improvement is fairly recent and is attributed to a pedagogical shift in the course toward more collaborative, problem-focused, and learner-centered.

Beginning in fall, 2012, Geosciences will require that all undergraduate majors participate in the formerly optional career-planning course that was offered as a follow-up to early versions of Fundamentals. Because the career-planning course (formerly Geoscience Fundamentals II) was not part of the required core, too few students took advantage of it. That changed in spring 2012. Geoscience Fundamentals will now explicitly encourage undergraduate majors to become more cognizant of both the variety of career options available to them, and the skills and habits of mind they need to compete for geoscientific and related careers.

Following construction of a new Scale-UP style classroom in 2009, Fundamentals has used a largely collaborative problem-based learning pedagogy in class, which requires that students prepare in advance of class. Using a workshop format, the collaborative environment provides a platform for students to carry out limited team-based research projects on an authentic problem and engage with diverse geoscience professionals. We attribute recent gains in writing and speaking to this new classroom-learning environment.

From its inception, Fundamentals has been writing intensive but more recently has used an inverted classroom format in which students acquire and are quizzed on basic information prior to attending workshop meetings. During workshop, they apply this information to in-class activities. These activities emphasize using the methods, philosophies, and communication forums of the geosciences. The activities range from debating whether facts are separate from values, to researching and writing about an authentic geoscience problem, to developing a compelling electronic portfolio that demonstrates learning, mastery, and a career plan, to engaging with geoscience professionals about the knowledge, approach, and skills they use to address their daily activities and challenges. By the end of Fundamentals, students will have completed weekly formal pre-meeting responses and post-meeting reflections, a collaborative written research project including a poster and a formal oral presentation, built an electronic portfolio that will be expanded upon in subsequent coursework, and created electronic promotional career materials (e.g., resume, career envisioning statement and plan, and sample cover letter). Throughout all of these activities, students are asked to engage with and reflect on whether and how the way they think about doing science has evolved or is evolving. Indeed, our pre-/post-assessments indicate that students' ways of thinking about the act of doing science has evolved over the years that Fundamentals has been a required part of the undergraduate curriculum. Students report that the course "makes them think", and "challenges their assumptions about science" in ways that traditional content courses do not. While anecdotal, these statements are encouraging, especially when coupled with increasing performance scores on graded assignments over the course of the program. These data suggest that making the methods and philosophies of science increasingly explicit in our teaching and requiring that students not only write and revise, but be held accountable for writing according to the appropriate forums and protocols for scientific communication reaps significant benefits in student learning and thinking over the course of the program and beyond. As the course continues to evolve, it is my fervent hope that no student graduating from VT feels significantly disadvantaged when they embark on their first job or undertake graduate work.

Differences in the methodology and justification of the field sciences and the classical experimental sciences

Carol E. Cleland
Department of Philosophy
Center for Astrobiology
University of Colorado (Boulder)

Experimental science has long been held up as the prototype of "good" science. Yet many scientific hypotheses cannot be tested in the classical manner of experimental science, namely, by means of experiments in controlled laboratory situations. Historical hypotheses about long past, natural events (e.g., the hypothesis that the continents were united in a supercontinent 250 mya and the hypothesis that the end-Cretaceous extinctions were precipitated by the impact of an enormous meteorite) provide especially salient (but not the only) illustrations. Such hypotheses are "tested" by searching for and identifying telling traces of the past in the messy, uncontrollable world of nature (in the cases at hand, respectively, patterns of frozen magnetism in igneous rocks and high concentrations of iridium and shocked quartz in K-T boundary sediments). As I discuss in several papers (Cleland 2001, 2002, 2011) such research is quite different from what goes on in classical experimental science. Yet as I also explain, it is a mistake to conclude from this that the former is somehow inferior to the latter.

The target hypotheses of most historical scientists is on large-scale, particular past events, e.g., a specific mass extinction event, such as the end-Cretaceous, as opposed to mass extinctions in general. Such events cannot be directly tested in a laboratory scenario because they are unrepeatable and moreover too large in scale to be artificially replicated in a laboratory setting. Given this difference in scientific focus it is hardly surprising that the practices of historical scientists differ in significant ways from those of classical experimental science. Prototypical historical research exhibits a distinctive pattern of evidential reasoning characterized by two interrelated stages: (1) the proliferation of multiple, competing, alternative hypotheses to explain a puzzling body of traces (present-day effects of past causes) encountered in fieldwork; (2) a search for a "smoking gun" to discriminate among them. A smoking gun discriminates among rival historical hypotheses by revealing that one (or more) provides a better explanation for the total body of evidence available than the others. While historical research involves a significant amount of laboratory work (to sharpen and interpret attenuated traces) it is different from what typically goes on in classical experimental science (Cleland 2002).

The differences between historical natural scientists and classical experimentalists in methodology are underwritten by a pervasive time asymmetry of causation well known to physicists (Cleland 2002). This *asymmetry of overdetermination* (as it has been dubbed by philosophers) consists in the fact that most local events (broadly construed to include material and structures) *over*determine their past causes (because the latter typically leave extensive and diverse effects) and *under*determine their future effects (because they rarely constitute the total cause of an effect); put simply, the present contains records of the past but no records of the future. Historical scientists exploit the overdetermination of past events by their localized present-day effects by searching for telling traces of (aka smoking guns for) hypothesized past events, and because most events leave many such traces in the environment they can never rule out finding them; it is this that justifies the search for a common cause when faced with a body of puzzling traces discovered through field work (Cleland, 2011). As an illustration consider an explosive volcanic eruption. Its effects include extensive deposits of ash, pyroclastic debris, masses of andesitic or rhyolitic magma, and a large crater. Only a small fraction of this material is required to infer the occurrence of the eruption. Indeed, any one of an enormous number of remarkably small subcollections of effects will do. This helps to explain why geologists can confidently infer the occurrence of long past events such as the massive, caldera forming, eruption that occurred 2.1 mya in what is now Yellowstone National Park.

In contrast, predicting even the near future eruption of a volcano, such as Mt. Vesuvius, is much more difficult. There are too many causally relevant conditions (known and unknown) in the absence of which an eruption won't occur. This underscores the other side of the asymmetry of overdetermination, namely, the *under*determination of the future by localized events in the present. Classical experimentalists attempt to circumvent this problem by conducting their investigations within the artificial confines of a laboratory where (unlike events in the messy uncontrollable world of nature) they have some control over potentially interfering factors. For it is always possible for a prediction to fail (or succeed) for reasons independent of the falsity (or truth) of the hypothesis concerned. This makes predictive work, such as is involved in volcanology or studies of climate change, especially problematic because such systems cannot be artificially replicated within the artificial confines of a laboratory; while computer simulations are invaluable they are primarily theoretical and hence should be carefully distinguished from experiments.

In summary, because our universe is characterized by a physically pervasive, time asymmetry of causation, scientists engaged in historical and experimental research find themselves in very different evidential situations and their practices reflect these differences: Historical scientists exploit the *over*determination of the past by the localized present by searching for a smoking gun in the messy, uncontrollable world of nature to discriminate among competing hypotheses about long past occurrences; such a trace(s) is likely to exist (but not necessarily easy to recognize) because the present contains so many traces of past events. Experimentalists, on the other hand, are faced with the *under*determination of the future by the present and attempt to circumvent it by controlling for false positives and false negatives, which are always a threat when predicting future events. In closing let me also note that I have recently begun investigating the methodology and justification of the non-historical field sciences; see Cleland & Brindell (forthcoming) for some preliminary thoughts. I look forward to some lively discussions on this topic at the upcoming workshop!

References

Cleland, C. E. and Brindell, S. (forthcoming): "Science and the Messy, Uncontrollable World of Nature," in Pigliucci, M and Boudry, M. (eds.), *Philosophy of Pseudoscience: Reconsidering the Demarcation Problem* (University of Chicago Press) (in press).

Cleland, C. E. (2011): "Prediction and Explanation in Historical Natural Science," *British Journal of Philosophy of Science* 62, pp. 551-582.

Cleland, C. E. (2002): "Methodological and Epistemic Differences Between Historical Science and Experimental Science," *Philosophy of Science* 69, pp. 474-496.

Cleland, C. E. (2001): "Historical science, experimental science, and the scientific method," *Geology* 29, pp. 987-990.

Field-experiences in every geoscience class: the key to facilitating developmentally appropriate instruction

Sean Cornell, Geography and Earth Science, Shippensburg University of Pennsylvania

Whether planning for an introductory, non-majors course or an upper-level major's class, I know that I must integrate at least one field experience into the class, if not more. At any university facing budget challenges, this is more easily said than done, and yet it is perhaps one of the most important tenants of my teaching philosophy. The challenge of getting between 72 and 118 non-major students nearly every semester into the field is one not undertaken by any of my colleagues. The time investment and logistics of getting non-major students into the field is significant and often not without major headaches. Numerous weekends and evenings are consumed in the effort, much to my wife's dismay. Yet student evaluations on the "best part of the course" retort the value and impact on learning that these efforts achieve. So why do a field experience in every class?

Ultimately, it is as much about inspiring students, as it is about teaching the methods of geoscience and connecting students to developmentally appropriate methods of learning. In the past, many young people had opportunities to access, observe, and investigate the outside world whether through playing in fields, forests, seashores, streams, or other natural places. Unfortunately, few students are afforded the same opportunities today. It is sad, but true. Young people today have few opportunities to interact with and explore natural environments; therefore, many students are disconnected from the natural world, as are their powers of observation. The reality is that educators have long suggested that most learners learn best when active, hands-on learning strategies are employed. Direct sensory experiences that generate discovery are more powerful as learning experiences when compared to other learning strategies. When students sit in a classroom in front of a chalkboard, they are disconnected from the environment physically and developmentally, and for most, this often results in a learning-handicap. For these reasons, field experiences in geoscience classes are critical to helping students learn not only basic concepts, but also contribute to learning the methods of geoscience that are rooted in observation, and asking questions.

Simply put, field experiences offer students opportunities to hone their observational skills and to apply abstract and process concepts learned in the classroom.

Since the geosciences rely so extensively on mastery of spatial-temporal concepts and process visualization, all requiring development of higher-order thinking skills, part of my teaching approach is to immerse students in environments where they are required to make observations, ask questions, and connect components of the physical landscape with underlying geologic concepts. For the purposes of this essay, I illustrate my approach through two courses... one an upper-level field research course and the other a general education Introductory Geology class.

In the latter, at the outset of the class, I provide students with a laboratory that explores and visualizes geoscience data sets using technology (i.e. through GeoMapApp, Google Earth, etc.) in order to initiate discussions of plate tectonic concepts. These inquiry-based approaches require that students investigate plate tectonic environments, topography/bathymetry of continents and ocean basins, the distribution and pattern of earthquakes, volcanoes, age of the sea-floor, and more. Students are then required to use their textbook as a way to research and explain their personal observations. Although many students struggle with the lack of "structure" that they have become dependent upon, they are forced to become active learners. They have to find words to describe what they have visualized and the vocabulary and concepts to explain their observations. These efforts provide the student with a baseline of observations with which they can then relate additional concepts through subsequent lectures and ultimately the field experience for the course. Fortuitously, our geographic location in the middle of the Great Valley of central Pennsylvania permits a follow-up field experience that includes an overview of field-evidence for timing and development of Alleghenian Orogenesis during the formation of Pangaea. In the same day, we are also able to explore the consequences of rifting processes that took place in the Gettysburg Basin during the Triassic to early Jurassic. In this way, the field-experience is integrated into the scaffold produced during earlier inquiry-based activities. Students are afforded significant opportunities to visualize and contextualize their observations into their own mental frameworks to support long-term retention of the information.

In the upper-level field-based course, my approach is to immerse students into a field-experience where learning is to some degree "unstructured". This semester-long course is initiated by an international travel experience (to Curaçao) prior to the start of the semester. Students have minimal experience in the geography/geology of the region and are forced to reconsider all preconceptions in such a way as to once again render students vulnerable to their surroundings. The physical and human landscapes are completely alien to most students so few students can rely on previous assumptions. Every observation is a new observation that must be considered, qualified, and integrated into existing knowledge base.

To further challenge them, students are immediately required to identify a research question that they are responsible for exploring and championing through the rest of the course. Daily field-excursions provide an overview of both the geologic history and the human-history of the island so that students have a framework to which they can relate. Near the end of the field experience, several days are allocated to student research. Students collect observations, work to refine their research questions, and initiate data collection as possible. For the remainder of the semester after the field experience, students contextualize the significance of their research question, establish baseline knowledge of the pertinent literature, perform data analyses, and draw conclusions. Throughout the process, students share their learning with other students in seminar discussions, and ultimately present their research at the all campus research day. This method of instruction appeals to the innate engagement in discovery and exploration mentioned previously, and arguably reflects the true nature of scientific research. Rather than engaging students in scientific discourse entirely through textbook methods, the methods outlined here require students to explore scientific methods by using the same processes used by practicing geoscientists. In my experience, this results in a more cohesive learning experience that not only allows students to develop background knowledge, but also forces improved observational skills, and opportunities to employ critical thinking skills that use inference and deduction to draw reasonable conclusions. Likewise, these approaches are aligned with developmentally appropriate methods that reach most learning styles.

Supporting Attachments

Geospatial and Geosocial Education

Declan G. De Paor, Spring 2012. ddepaor@odu.edu

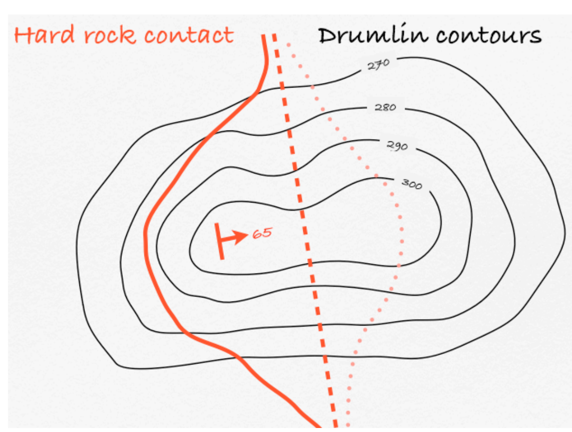
The following were my undergraduate courses at University College Dublin, Ireland:

> 1969-70, 1st Year: geology, mathematics, physics, mathematical physics,
> 1970-71, 2nd Year: geology, mathematics, physics,
> 1971-72, 3rd Year: geology, mathematics,
> 1972-73, 4th Year: geology.

Of course, chemistry and biology were on offer, however in 1st year each required two afternoon labs whereas physics had one long lab and geology ran morning labs plus weekend field trips. I thus had four afternoons free for student life (protest marches, *etc.*)

After classes started, my motivation for studying geology changed from convenience to interest thanks to Dr. Pádraigh Kennan's lectures. Before class, he painstakingly covering blackboards with legible handwriting and multicolored chalk illustrations that shared the destiny of sand mandalas. I think we concentrated harder knowing his wisdom was about to be erased forever. Everything I learned in geology was new whereas physics and mathematics classes regurgitated the secondary school curriculum. Department Chair, Prof. Brindley, didn't permit the teaching of plate tectonics but our lecturers would meet us in the campus bar and subversively report on the unfolding geoscientific revolution (I particularly remember a demonstration of lithospheric thinning using Guinness froth). The geology program included many field trips and often we ended up in a pub discussing the day's work with instructors (or singing rugby songs, or both). The social aspect was central to our learning; there was no continuous assessment, but we studied in order to hold our own in these discussions. Geology labs also involved collaborative learning. Long before physicists designed SCALE-UP (www.ncsu.edu/per/scaleup.html), we gathered around specimen boxes or maps and exchanged observations peer-to-peer.

For my senior thesis, I mapped a contact aureole whilst my physics friends measured tracks in a Wilson Chamber. They weren't sure mapping was 'real' science and liked to quip that science was either physics or stamp collecting. But they envied geo students.



Geology did not come naturally to me. I had to work hard to see what was obvious to others, such as the mineralogy of fine-grained rocks or the justification for calling something *hornfels*. Prof. Brindley was interested only in solid geology and viewed anything younger than Carboniferous as 'cover.' I struggled to draw a hard rock contact across a drumlin. First, I used strike lines to trace the contact but Brindley said that was wrong, that I should draw it straight across. I considered this but curved the contact in the opposite direction, arguing that ice had probably scoured the underlying bedrock into a spoon-shaped depression. Brindley responded: "Draw the contact straight across the drumlin, or is it that you think you're the only student I have to supervise?" I decided I didn't understand map making and resolved to research things I could measure, calculate, and be sure about.

After five years teaching in Galway, I moved to Johns Hopkins and offered mainly advanced courses. The audience for mathematical geology was not large, however, neither among students nor colleagues. I endeavored to make conference presentations about tensors entertaining and colleagues would respond "Loved your talk - didn't understand a word of it - ha!" I decided the only way to promote my topics was to offer faculty workshops using lots of graphics. Visualizations helped folks grasp complex processes, while making and presenting them improved my own understanding.

My interest in computer graphics coincided with a 'two-body' career path ranging from contract-teaching a class of five majors at Harvard to team-teaching (with two physicists and two astronomers) in an auditorium filled with 425 students of Boston University's Core Curriculum. Team-teaching with people Rutherford would have called scientists lead to many discussions on scientific method.

I also directed BU's Field Camp at a time when GPS and GIS were revolutionizing mapping and came to the conclusion that mapping was key (pun intended). Geology describes places that change through time; it uses methods from Steno, Smith, Hutton, Walther, *etc*. The *Principles* in Lyell's book are not derivable from Newton's *Principia*. Earth cannot be reduced to physical particles bound by chemical bonds, because complexity emerges from their interaction and emergent complexity spawns chaotic patterns that require map making and map interpretation.

My Core Curriculum colleagues pointed to the role of prediction, *e.g*. Einstein's 1915 prediction that starlight would be deflected by the Sun which was dramatically confirmed during a 1919 eclipse. However, that prediction then became an explanation of the past. Explanations of the past in geoscience are as valid as future predictions in physics.

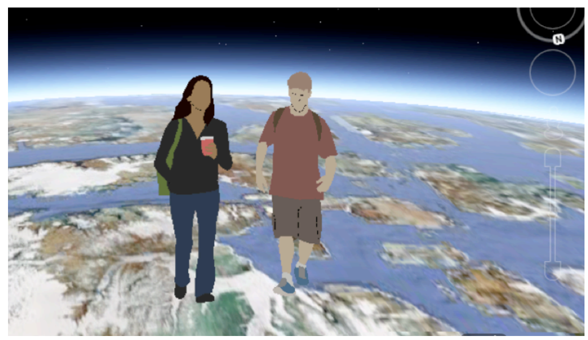
Another hot topic for discussion was Popperian Falsification – the notion that a hypothesis could never be proved by repeated tests but could be falsified by a single negative test. This is not what Karl Popper actually said, and is not how science works. When a test result is negative, the hypothesis may indeed be wrong, or the test may be flawed. Whether a result is positive or negative, the test may be tainted by fraud. And if you test whether a test is valid, the problem becomes recursive. So how can you know?

Consider an analogy with jigsaw puzzles – a hobby my spouse Carol Simpson and I occasionally found time for before e-mail. Some pieces fitted uniquely but in regions of blue sky, alternative fits seemed equally possible. We turned these pieces over and examined the cardboard fabric closely. If pulp matched across jigsaw-cuts, we knew the fit was right. A similar approach works in geoscience. Wegener noted general coastline correspondence, then Bullard matched continental shelves in detail. Problems with the

Bullard fit, such as Iceland and Iberia were resolved on even closer inspection – Iceland was young, Iberia had rotated, *etc*. Thus, the key to resolving at least some working hypotheses is pattern recognition across a range of length and time scales. The proof is in the zoom-in!

As Carol pursued the dark art of academic administration, I continue to move (with the onset of middle age, finding a new spouse-job seemed marginally easier than finding a new spouse). WPI had no geology department so, invoking *karma*, they put me in physics. From there, I taught planetary science and geology for engineers. To my surprise, some of the smartest engineers disliked graphical solutions; rather than find the intersections of two planes by using a stereonet, they preferred to calculate with direction cosines and cross products.

Now in ODU's physics department, I teach 375 non-majors (many from disadvantaged backgrounds) about the Solar System. Most have no understanding of the scientific, not to mention geoscientific, method. My research group creates, tests, and disseminates 3D models of specimens, block diagrams, *etc*., for use in Google Earth™. We've developed interactive virtual field trips and a mapping game in which students' avatars explore Google Earth at various scales (why not?) and communicate *via* text messages that pop-up in one another's placemark balloons.



I also teach with the Omniglobe™ and offer planetarium "field trips" to school children and the public. Digital full-dome projection of the planets and moons opens up new, immersive modes of both formal and informal education.

Geoscientists are not the only scientists who deal with places and patterns, but these are at the core of what we do. In today's world, few students can learn the methods of geoscience in the field-based, highly social environment that many of us experienced. Our new challenge is to bring that social-learning approach to the domains of general education, adaptive learning, distance education, and peer-to-peer instruction.

Links:

www.digitalplant.org
www.odu.edu/~ddepaor
www.odu.edu/planetarium
geosphere.gsapubs.org/content/8/2/491.abstract
www.sciencedirect.com/science/article/pii/S0098300410001755
www.geosociety.org/gsatoday/archive/20/4/article/i1052-5173-20-4-4.htm
www.geosociety.org/penrose/10google.htm
www.geosociety.org/meetings/2012/sessions/keynote.htm
NE GSA Workshop, Bretton Woods NH, 2013. Building Google Earth Geologic Maps and Information Systems for Desktops, Laptops, and Mobile Devices.

Introducing the Methods of Geoscience to Physical Geology Students
Beth Dushman

As a geology instructor at a community college, I teach mostly non-majors students in my Physical Geology lectures and labs. These classes may be these students' only introduction to science at a college level, and it may be the first science class they have had in years. These students are often science-phobic and lack the confidence to engage in discovery learning. At the same time, I often have a few majors in my classes. Thus, my challenge is to teach the majors geoscience skills they will need for future classes, while engaging the rest of the class in activities that will improve their understanding of basic science and geology. The most important methods of geoscience that I think students should learn in my classes are critical reasoning, observation of natural phenomena, synthesis of multiple ideas, the basics of how the scientific method is applied in geology, and communicating scientific information.

I use a variety of strategies to teach these science methods in my lecture and laboratory classes. I start each semester with an overview of the scientific method, and compare the traditional 5-step process (observation, hypothesis, experimental design, data collection and analysis, and conclusion) to how the scientific method is applied in Geology. For example, many students learn that science is conducted through experiments with strict controls and a few variables. Geoscientists, however, lack an extra planet to use as a control when we study the Earth. Instead, we make approximations in labs and using computer models, but often data are gathered through field observations.

As the class investigates various topics in geology, I explicitly identify ways in which the scientific method (and other geoscience methods) has improved our understanding of the Earth. The development of the theory of plate tectonics works an an excellent example. We discuss the initial observations, gathering of evidence, original ideas and criticisms about continental movement, through the discoveries that resulted in the theory of plate tectonics. Throughout the semester, I encourage students to ask, "how do we know that?" about any topic. Each time this question is raised, it presents an opportunity to share the observational and analytical methods that laid the foundation for our current understanding of that geological phenomenon.

Of all the science methods my students should learn, critical reasoning skills are the most important. Critical reasoning is essential in most fields, and yet students are often overwhelmed by any problem that requires effort beyond simple memorization and regurgitation. This problem may be compounded by the perception that science is too hard, or that students are "bad at science." As a way to demonstrate to my students that they can be competent problem solvers, I work with them to break problems down into simple steps, and then to integrate those steps to make a whole story. For example, while interpretation of a simple stratigraphic section may be daunting at first, students gain confidence as they decipher the geological history of that area.

In my lab classes, students apply some of these methods through hands-on experimentation. For example, students practice observation of natural phenomena in lab exercises using stream tables and Google Earth, while simultaneously synthesizing information from lecture, lab, and observations. As part of the lab where students experiment with small stream tables, students are asked to describe how the models succeed or fail at approximating Earth processes. This question helps to engage students in a discussion of the limitations and advantages of using models in geoscience in general.

Another important geoscience method is clearly and effectively communicating scientific information. My students complete a writing assignment for which they must find and evaluate sources of scientific information, then summarize into a coherent synopsis of a significant geologic event. This exercise introduces students to how scientists collect, interpret, and communicate their data. While the students are not conducting original research for these assignments, this project may be their first introduction to scientific reseach. Furthermore, by delving deeper into the information available for a given geologic event, students begin to recognize the differences between scientific media and popular media. For majors, this project gives students an idea of where to start looking for science resources and introduces them to the peer-review process. For nonmajors, students gain an appreciation for how scientific information is developed and disseminated to public.

Prior to taking this class, many students were only exposed to geology when natural disasters occurred, resulting in a somewhat skewed perception of the role geologists play in forecasting or mitigating these events. By developing a deeper understanding of the ways in which geoscientists study the earth, students are better able to assess the information they see in the mainstream media. To this end, we discuss methods geologists employ to study hazards, such as seismic surveys, mapping of earthquake foci, gravitational studies, and volcanic hazards monitoring, and how geologists describe risk using recurrence intervals. Then, when we address the limitations of these methods as applied to natural hazards, students recognize why we cannot predict or prevent many geological events.

Lastly, any discussion of how science works should include a discussion of how scientific thought changes over time. I emphasize that while geologists do have a very strong framework for contextualizing most Earth processes-- Plate Tectonics-- there is still a lot about how the Earth works that we do not yet understand. As students consider applications of geoscience methods to these unanswered questions about the Earth, they gain an appreciation for ongoing geological research. Even better, some are inspired to become geoscientists themselves.

Lithic Literacy and the "Forensic" Methods of Geoscience

James R. Ebert, Department of Earth and Atmospheric Sciences
State University of New York, College at Oneonta

My approach to teaching the methods of geoscience is founded on two related expressions of a single idea, which I use in nearly all the courses I teach. The first expression is in the form of a question that I often pose to my students: "What do we know and how do we know it?" It is the "how do we know it" part that encompasses the methods of geoscience. The second expression is borrowed from Murray (2004) – it is the notion that all geology is forensic geology. I do not mean the legal aspects of forensic, rather I mean the association that the word has with the reconstruction of events and processes from the physical evidence of those events and processes.

So, how do we know what we know and how can we reconstruct events for which there are no eyewitness accounts? The clues are "written in the rocks." However, before students can read the story they must develop what I call "lithic literacy." By this, I mean that it is first necessary to be able to recognize the clues before we can interpret them. In my classes, I stress the centrality of observation in the solution of geoscience problems. Bill Metzger, with whom I studied historical geology and stratigraphy as an undergraduate, often said, "Interpretations come and go, but a good description lasts forever." In developing lithic literacy, it is not only important that students make careful observations, but they must also come to realize that some observations are more useful than others are. For example, the texture of any rock provides clues to the processes that formed that rock. Observations of texture are generally more useful than observations of color, which may be influenced by weathering or the presence of trace elements.

Once students gain some facility with observation, I introduce interpretation by starting with modern analogs that are familiar to most students. Because I teach courses in Earth History and Sedimentary Geology, I use sedimentary structures. Most students have seen ripples and mud cracks in modern settings, so it is not a giant intuitive leap to interpret such structures when they occur in rock. Students quickly recognize that these structures are records of processes, unwitnessed, but which undoubtedly occurred. This is the geological version of "Who done it?"

From sedimentary structures, we reconstruct processes. Processes lead us to environments and from environments to paleogeography. This inductive approach differs somewhat from the other sciences in that we are working from multiple specific examples and deriving general principles. Other sciences tend to use a more deductive approach. On the other hand, once paleogeographic and stratigraphic frameworks are established we can make predictions to unexamined areas. Can we project how thickness, facies, etc. will change in these areas? These predictions are hypotheses, which are testable by observations in the unexamined areas. In this respect, the methods of geoscience do not depart radically from the methodologies employed by other sciences. However, geologic systems are inherently complex and commonly messy, unlike much of chemistry and physics, for example, in which controlled experiments, which manipulate one variable at a time, are the norm. Students commonly struggle with the uncertainty inherent understanding in complex, messy geologic systems. All scientific knowledge is tentative, of course, but students are not comfortable with the notion that their interpretations might be wrong. Further, they do not like the notion that there are other, possibly better explanations, which they have failed to envision. Part of my task is to help students develop some level of comfort with this uncertainty.

References Cited

Murray, R. C., 2004, Evidence from the Earth, Mountain Press, Missoula, MT, 226p.

Want better-prepared students? Teach teachers to think like geoscientists

Amy Ellwein, Geology Program, Western State College of Colorado

Among other courses, I teach inquiry-based, integrated lab-lecture science courses for pre-service elementary teachers with limited enrollment. As opposed to geoscience majors, this audience typically has a weak background in science and math and considerable trepidation about learning, and ultimately teaching, science and math. I also develop and teach field-based professional development geoscience courses for in-service K-12 teachers, which is an audience that has experience teaching in K-12 settings and is seeking deeper knowledge and skills. In many ways, teaching geoscience courses for teachers is quite similar to teaching courses for geoscience majors; the same challenging concepts are highlighted and all students work to gain conceptual knowledge, discipline-specific skills, and an understanding of the nature and processes of science. However, one major additional goal in geoscience courses for teachers is that learners must sufficiently and confidently master major geoscience concepts and methods in order to effectively teach geoscience.

I find that establishing a highly interactive student-centered course is critical to teaching the methods of science. Also critical are fostering mutual respect, enthusiasm for experimentation, and acceptance of failure as an important step in deep learning. In my small courses, I've found that combining science notebooks with reflective writing promotes these critical course components. My students use notebooks daily to learn and model some of the processes of science: recording data, observations and questions; building and testing hypotheses; summarizing results, etc. But they also use notebooks to identify and challenge their currently held preconceptions, build on their existing knowledge, monitor their ongoing learning and thinking about concepts or methods, and reflect on course activities and their learning progress (e.g. Reflective Writing Prompts).

Careful, standardized, and repeatable field observations, in the context of conceptual or numerical models, are the foundations for what we know about the Earth and Earth Systems (and how we know it), but my students often don't consider their observations as scientific data. Teaching students to make quality observations in the field, to find patterns in their data, and to clearly separate observations from interpretations, are important activities that result in skills that are highly transferrable to other sciences and scientific thinking in general. The related concept of multiple working hypotheses is also very difficult for many students, in part because asking scientific questions is daunting for many novices, but is key in understanding how to "think like a geologist". I think it is very important that pre- and in-service teachers have ample opportunity to make basic field observations and interpret geologic data in order to understand, use, and ultimately teach, the methods of geoscience in their own classrooms.

Supporting Attachments

Want Better-Prepared Students? Teach Teachers to Think Like Geoscientists (Acrobat (PDF) 60kB May14 12)

Geoscience odd-(wo)man out
Holly Godsey

My experiences in teaching to date have been anything but traditional. They include a couple of TA positions, field camp for non-geoscience majors, graduate student seminars, teaching high-schools students while floating through Cataract Canyon of the Colorado River (Quick! Name the type of rock that we are about to smash into!), and various efforts in my son's elementary school classrooms.

For the past eight years, I have managed and directed several science education programs including two NSF GK-12 programs, an NSF Noyce Teacher Fellowship program, and a Masters of Science for Secondary School Teachers program. Through all this time I have organized and sat through countless teaching and pedagogy seminars, created lesson plans, taught inquiry-based methods, mentored graduate students on their teaching, lead sessions on effective communication, created teaching kits, and managed to NEVER teach a course in geology.

However, that is all about to change for me as our university is embarking in a new program in Earth Science Teaching and I am the one leading the charge. I am thrilled that I have the opportunity to participate in the Geoscience Teaching Methods workshop and learn from others that have been doing this for years. I will have my first opportunity to teach in a formal setting this fall in rocks and minerals course for teachers.

I have several goals for my career as a teacher of geoscience, some are personal goals and some are intended to affect a change in how Earth science is perceived in the Utah state educational system. Personally, I want to do what every teacher wants to do and that is to excite and engage students in Earth science. I want to learn to clearly explain difficult concepts and effectively communicate how these concepts are relevant to the world we live in. I want to engage students in minds-on, and inquiry-based activities that help them develop their own pathways to understanding and give them the tools to integrate multiple data sets to form a coherent model of Earth processes.

In Utah, Earth Science is taught in 9th grade and is considered a "default" course for those students who do not have the aptitude for biology, physics or chemistry. The teachers that teach Earth Science typically have little training in geology (you can be endorsed to teach it with just one geology class) and teach it as an "extra" to their biology and chemistry courses. Therefore, the subject is typically taught lecture-style with very little inquiry or research-based methods.

As geoscience professionals, we all understand that the methods of geoscience research are very different than those of biology or chemistry and that the standard "science-fair model" does not work well for this discipline. Teachers do not understand how to teach geoscience as a research-based science when they can't do a repeatable experiment in a test tube. This misconception has permeated all the way up to the State Board of Regents who deny Regents Scholarships to students who take Earth science because they do not recognize it as a research-based science. Ironically, geoscience is the ultimate research-based science and requires concepts from math, chemistry, biology and physics to gain a complete understanding of Earth processes. Earth Science should be viewed as a 12th grade "capstone" course that other sciences are the prerequisite for (and, in fact, we are piloting such a course this fall). My ultimate goal, therefore, is to train teachers to teach Earth science as Earth science is done and eventually raise the bar for geoscience teaching in my geologically-gifted state of Utah.

Thoughts on Teaching the Methods of Geoscience
Kyle Gray – University of Northern Iowa

For the past three years, I have been teaching at the University of Northern Iowa – a four-year, public university with a strong emphasis on teacher education. Like many of the institutions represented by participants in this workshop, UNI was formerly known as a teacher's college (Iowa State Teacher's College) and still maintains a state and regional reputation as "the place to go to become a teacher". I am housed within the Earth Science Department but also teach courses for the secondary Science Education program.

I am a relative new-comer to the field of teaching the methods of geoscience. Over the past year I have read several papers describing the key differences and talked with several people in our community about this topic. From my perspective, geoscience inquiry has historically been about observing some phenomenon the natural world (e.g. look at the rocks at a given locality) and determine how or why that phenomenon happened (e.g. determining how these rocks formed). Put another way, geoscience inquiry often takes the form of "What's over there and how did it come to be that way?" This is an inductive approach to scientific inquiry that often includes a historical questions (When did that happen?). This methodology is shared by other disciplines including astronomy, meteorology (both of which could be included within the term *geoscience*) and stands in stark contrast to the deductive "science fair model" of science where an investigator always proceeds in order through the steps of hypothesis, experiment, results, and conclusions.

My primary teaching responsibility is an Earth Science content course for pre-service elementary education majors. This is an inquiry-based course with students who are primarily freshmen and sophomore women who have avoided taking science in high school and have not had an Earth science course since middle school. At the beginning of each semester I have the students write a reflection paper on their prior experiences in learning science as well as their views of the ideal way to teach science. At the end of the semester I have them reflect on what they have learned and areas in which they have grown in their understanding of the nature of science. I also collect data on their beliefs towards teaching science. Each semester, my students consistently report that they view science as a single, monolithic process that must be rigorously followed. One student even described how she originally thought that scientists only 'did" science when they were using the periodic table. This rigid structure turns many students off to science. By the end of the semester, many express their joy in learning that scientific inquiry is more than conducting experiments.

As I reflect on my teaching, I realize I have been incorporating explicit teaching on the methods of geoscience in my courses. In my inquiry course, my goal is to give my students multiple opportunities to engage the data or phenomenon so they can practice those science process skills of collecting and analyzing data as well as using those data to construct explanations based on known scientific principles. For example, when talking about soils, I have students observe photographs of different types of soils from around the world and then use their observations to identify similarities between soil types. These similarities are then used to define a soil. Another example is my lesson on the behaviors of meandering streams over time. The students observe geomorphic changes in a stream table and infer the general rule for erosion along cut banks. Then they observe a series of Google Earth images from the Wabash River showing numerous abandoned meanders and ox bow lakes and use their previously developed model to interpret the river's history. Even though I have included the nature of geoscience inquiry in my courses, I am looking forward to finding new ways to improve this aspect of my teaching.

Besides reflecting on my own teaching, I have thought about the challenges and barriers we face in communicating the methods of geoscience inquiry and geoscience thinking. The first is the diversity of student populations with whom we are teaching. Geology majors need to a different and deeper skill set than a pre-service elementary teacher. While there will certainly be some overlap in the lessons and activities used to teach each group of students, my guess is that some activities may be needed that specifically target only one group. Second, teaching to think and act like a geoscientist requires significant time outside of the classroom making direct observations of the natural world. Looking at hand samples of limestone and sandstone is not the same thing as standing at an outcrop containing these rock types. Even looking at a picture is not the same experience. From such field experiences, students should come to understand that all products of geoscience inquiry (e.g. geologic maps) began as human interpretations of field relationships like those shown at outcrops. Third, geoscience is a context-specific, place-based discipline that cannot be replicated in all classrooms. Students conducting a chemistry experiment should have the same experience in both Alabama and Zanzibar. For laboratory disciplines like chemistry, place does not matter, but in the geosciences, the location of the classroom greatly influences student learning. Students in Iowa have multiple personal experiences with tornadoes but cannot easily visit a volcano. Similarly, students in the Pacific Northwest have access to volcanic rocks and volcanoes but students in the Midwest do not. These challenges are magnified for those trying to teach in an online medium. Fortunately, advances in simulations and geospatial technologies (like Google Earth) can compensate for the lack of experiences by our students, and I wonder if tools like this can convey the unique perspectives that geoscientists possess.

In the end, I see one element that runs throughout these issues, that is the need for students to directly practice doing geoscience in a real, authentic environment whenever possible. Some localities may provide a wealth of experiences whereas others may provide extra challenges. Also, given the state of many department budgets, it may not be possible to get out into the field very often, so activities that work in campus settings or within the classroom may play a critical role in teaching these skills to our students.

It’s scary to feel uncertain
Kim Hannula

About a month ago, I got a flyer in the mail advertising software to aid in three-dimensional visualization of geologic structures. “Reduce your uncertainty!”

I’m not sure that’s what my students need.

My department (at a public liberal arts college, with no graduate students) teaches students how geoscientists do science by getting the students involved in collecting and interpreting data, starting with class projects as freshmen and culminating in senior theses based on independent research projects. My introductory Earth Systems Science class collects and interprets data on a small local river. My sophomore mapping class writes a report that accompanies their final mapping project. My junior Structural Geology class writes reports that separate their observations from their interpretations for every field lab. Our seniors propose research projects during their junior year, collect their own data, and present their work as papers and professional talks at the end of their junior year. And my colleagues take similar approaches in their classes.

This semester, I taught Advanced Structural Geology, an upper-level elective taken by about ten junior and senior undergraduates. It’s the one course in which I can teach nearly anything I want, and this semester, the course was inspired by a pair of articles by Clare Bond and colleagues at Midland Valley, a structural geology software company. Clare had shown a synthetic seismic section to geologists at conferences and asked them to interpret it, and found that only a fraction of people with related experience had interpreted it correctly. The most successful approaches involved thinking about the sequence of events that formed the structures, rather than simply identifying the geometry. Midland Valley creates software that allows testing of structural geology hypotheses through various kinds of modeling, and at conferences, I’ve seen Clare argue that their software can be used to improve geologists’ understanding of hidden structures. I decided to focus my course around their software, and around the use of modeling in structural geology in general, in part because I thought Clare’s arguments were compelling, and in part because I was concerned that our undergraduates don’t give a lot of thought to what they are trying to accomplish when they use specialized software. But I didn’t just want the students to learn to use software – I wanted them to make a habit of thinking about the tools that they use to solve particular problems, to think about the underlying assumptions, to think about whether the software was testing the students’ conceptual models of their structures, or whether they were using the software to confirm things that they were already certain were true. The final project for the class was to apply the software (or another type of modeling software) to a structural geology problem, and to write a paper that discussed both their results and their assumptions.

I graded the final papers for both Advanced Structure and my introductory course last week, and as I read them, I wondered whether the process of collecting and interpreting data really helped them understand how science works. In paper after paper, the intro students told me that the river behaved exactly in the way that they expected (even though there were several strange results in the data – for instance, an unusually high discharge measured at one site, paired with surprisingly low turbidity). In paper after paper, my Advanced Structure students told me that the software worked because it reconstructed their cross-sections correctly, and that their cross-sections must have been right because the software said so. All of the students, intro and upper-level, were so *certain...* without good reason to be.

It made me think that maybe this whole process of science is just plain *hard* for humans. Not because we have to do math or physics or chemistry or scale shear cliffs while carrying thirty pounds of rocks, but because we don't like uncertainty. We don't want to look for those things that might show us that the world doesn't work the way we think it does. It's scary. It's stressful. And we're rewarded for being right, not for questioning ourselves.

And yet it's that questioning that makes science a valuable way to understand the world. If science brings us closer to an understanding of the natural world, it's because science tests its assumptions.

But if doing the kind of work that scientists do isn't enough to create a habit of open-mindedness, a willingness to examine one's assumptions and be aware of how those assumptions shape our results, what should we (as teachers) do?

I don't know. Here's an example of something else that I did, something that I thought worked, but which probably wasn't enough:

I took my Advanced Structure class on a field trip over spring break. In the middle of the field trip, I had them map in an area where they knew there could be normal faults, thrust faults, strike-slip faults, folds, overturned stratigraphy – almost anything possible at shallow levels of the crust. They had seen the basic stratigraphy, and they had aerial photos and compasses. I sent them out to figure it out.

After about an hour, I went looking for the groups. Some of them thought they had figured out the answer. Most of them were wrong, and I tried to get them thinking about what observations they needed to make to test their models and think about other possibilities. Other students were just confused, and frustrated, and needed coaching to start brainstorming possibilities. I sent them all off again with sketches of possible cross-sections and predictions that each cross-section implied.

In the van at the end of the day, I told them that being confused is part of the field geologic method. "Go outside. Walk around. Get confused. Sketch possibilities for what might be going on. Walk around some more and see if those possibilities match what you see."

But I think that in the end, they really wanted to be certain that they were right, whether the evidence was strong enough for their certainty or not.

Geoscience methods applied to real-world problems

Kathleen Harper, University of Montana Geosciences

Many students come into my Physical Geology course with the impression that they are going to be asked to memorize a long list of unfamiliar words and learn special facts about rocks. Most of the students enrolled in this large-enrollment lecture and lab course are taking it to fulfill a general science requirement rather than planning to major in geoscience. Few of them know much about geoscience coming into the course. My hope is that by the end of the term they will feel that they have learned how observation, measurement and modeling allow geologists to solve problems and answer questions. I also want students to recognize that some of the problems that geologists take on are very “relevant” to everyone on earth – not just geologists. Problems such as risks of earthquakes, volcanic eruptions and energy and mineral resource utilization.

I am always trying to add to my quiver of interesting geology-based examples of how the process of science works. Characteristics that make engaging examples seem to be one with relevance to regional issues. A few examples are problems involving the contamination, primarily of surface and groundwater, that is the legacy of mining in Montana (such as the example activity included here); energy resource issues, such as coal, oil and gas extraction, “fracking,” and using oil sands; and prediction of earthquakes and volcanic eruptions in the Pacific Northwest and Yellowstone region. I also like issues with global relevance such as the implications of changes in behavior of the Greenland Ice Sheet, or using paleogeographic reconstruction to understand why the Middle East has such vast oil and gas deposits. When students can see the application of knowledge to problems, they can begin to build an understand of what geoscientists – and other types of scientists – really do and what makes them passionate about science.

Curiosity based learning and self-education

Paulo J. Hidalgo, Geosciences, Georgia State University

I have always admired educators who were able to transform my lack of enthusiasm towards a subject into that of mesmerizing interest. Educators such as the ones I am referring to not only changed my career selection but have continued to influence and revitalize my appetite for knowledge and higher research standards. Like them, I believe that my role in the classroom is that of a instigator of scientific curiosity. Somebody that could bring back the primal curiosity embedded in human nature by encouraging students to self-educate.

I have an inquisitive, curious and precocious 3 year old daughter. Because of my scientific training, I tend to observe and analyze everything that she does, says, or observes. I have come to realize that she is naturally curious like many other children of her age. She continuously inquires about her surroundings and later generates concepts and models to describe the world around her. I have realized that commonly she tests these concepts over and over, modifying previous conceptions when needed. This I believe, is an endless curiosity based learning cycle. More importantly, this process is roughly akin to what we describe as hypothesis testing and the scientific method. From birth our children are wired to be more than passive observers. Their brains are free of preconceptions and are predisposed to perceive the environment with great amazement and inquisitive minds. This is possibly why children are able to learn by simple observation and listening, skills such as: walking, climbing, jumping, talking, learning new languages, physical properties of objects, psychology of interpersonal relations, etc. Children manage to learn all of this complicated plethora of complex skills from no one. It is by simple free play and their insatiable curiosity that they learn about the world around them.
Later in live, the insatiable minds are send to structured schooling where the self-inquiry self-education process could cease to operate.

George Bernard Shaw used to say:

> "The only time my education was interrupted was when I was in school." and
>
> "If you teach a man anything, he will never learn."

I believe that our role as educators is to try to reverse the "damage" that many years of structure schooling have done in our students minds. I believe that this is more easily done by creating a class environment that is conducive for students to teach themselves and others. But overall, by creating a community of supportive and collaborative inquiry within the classroom that is based in the common phenomena that we observe in the word around us.

Crucial to this process is to provoke the students curiosity by making them produce their own observations, and their own inferences and theorems based on the observations. Later, our role is to present the current state of the subject by introducing theorems and paradigms (carefully for the faint of heart), and empirical concepts that can be integrated into their own life experience. In the opinion of many developmental psychologist, curiosity is an important piece in a complex puzzle of dispositions that are necessary for lifelong learning. In that sense, our primordial activity as instructors should be to facilitate curiosity in our classrooms and evaluate how well we are developing lifelong learners by continuously assessing and reviving student's natural curiosity.

Supporting Attachments

Learning geoscience by doing geoscience – by Paul Kelso, Lake Superior State University

As is the case with many faculty, my teaching methods and strategies have evolved over the years. I learned geoscience primarily though traditional lab and lecture and this is how I initially structured my classroom. I lectured, did a variety of demonstrations and students applied concepts though laboratory activities and homework exercises. This appeared to be successful as students generally preformed well on assignments and exams.

After teaching for a number of years I became frustrated with student retention of material and their application of previously learned concepts to new situations. When teaching upper division undergraduate geology classes I often ask students to apply concepts that they learned in a previous class. I don't know if you have ever had this experience, but students would often tell me, "no we didn't study that in such and such class." Then I would inquire with colleagues and they would say yes we covered that material. Students would even tell me, "no you didn't cover that topic in class the previous year." After discussion of particular examples related to the topic that we had previously discussed and then they would begin remember that they had heard that before, but often had difficulty seeing the connection and applying these concepts to the new situation in their current class.

I have modified my teaching to try to address student's retention and application of concepts. Now student activities often model the professional geoscience experience, thus students practice working as geoscientists. This has involved a redesign of my courses so that they focus on the process of doing geoscience rather than the traditional discrete, content-centered courses. Courses now are problem-centered, concentrating on important geologic problems and emphasizes sub-discipline integration. Courses are structured to integrate fundamental geoscience concepts from sub-disciplines presented in the context of sequentially ordered problems that reflect increasing structural complexity, different depositional regimes, and different igneous and metamorphic petrogenetic models. Most courses have field component to promote in-depth understanding of real world geologic problems. Individual student projects are designed to promote the comprehension of fundamental concepts through its application to solve significant geological problems. The application of concepts to answer questions students have from their field based projects motivates students to learn, internalize, and apply concepts.

This course pedagogy is based on these key principles: learning is constructivist, experiential, investigative, inquiry-based, and collaborative within a community of student-scholars. Constructivist teaching/learning theories are applied that emphasize active learning which helps students construct a strong knowledge framework and enhances motivation, learning and retention, problem solving, critical thinking and communication skills. Active cooperative learning increases conceptual understanding and student achievement and helps students overcome misconceptions. In our paradigm, individuals actively construct new knowledge by building on what they already know while hopefully discarding misconceptions. Students develop higher level thinking skills and construct new knowledge by participating in a community of learners, by making observations and developing a conceptual understanding, while learning terms and facts, and by actively explaining their understanding of concepts. Learning progresses as students work collaboratively, discuss their progress, encounter different interpretations, bounce ideas from each other, and challenge each other's conclusions.

The focus on field based projects requires students to: make their own observations, decide what information is important to collect and how to collect it, often collect a variety of information related to different geoscience sub disciplines, revisit key concepts at increasing levels of sophistication on succeeding projects, decide what is not important, decide how to focus their time and energy give the project objectives and time constraints for the project. The identification of real problems for the students to address provides a context for the problem, generally requires students to consider concepts from multiple sub disciplines, and provides student motivation to solve the problem. This has resulted in improved student retention of materials and it application to new situations as they practice this on multiple projects.

Many of the projects are designed so students are involved in all aspects of a project. Thus the students must propose and justify the method to solve a problem, design the study, carry out the study through the collection of data, process and interpret the results, and present the conclusions/recommendations both written and orally. Thus projects model the work that a geoscientist might undertake working in industry or academia.

Developing activities where students learn the methods of geoscience by modeling the behavior of professional geoscientist has resulted in a significant change in what students learn and how they apply this knowledge to geologic problems. Students are now learning geoscience by doing geoscience. It is exciting watching students as they learn to answer and ask questions, as they tackle increasingly sophisticated problems and as their confidence grows as they develop as geoscientists.

Taught traditional geology lab lectures for years

Weakness –

Retention of concepts

integration of concepts from different disciples/courses to solve problems

differs substantially from traditional curricula in which knowledge is too often compartmentalized and students have difficulty making important connections among sub-disciplines.

Students learn by doing

requires student problem-solving and critical thinking, utilizes active learning strategies that model scientific endeavor, provides a focus for sub-discipline content application

Model professions geoscience experiences

Real world experiences solving geoscience questions

Students practice integrating information from multiple sub disciples to solve problems

Revisit concepts a increasing levels of sophistication in multiple courses

Focus on field based learning

Require integrating a variety of information

Collected information is often from multiple disciplines

Students have to learn what is important, what to focus their attention on

Why do we teach geoscience to non-majors?
Kaatje Kraft

In a recent homework assignment a student submitted about the nature of geoscience, he cited a webpage that discusses whether geology is a real science or not (http://www.quantumpie.com/the-big-bang-theory-sheldon-asks-is-geology-a-real-science/). The blog discusses how geology is different from some of the other traditional sciences because we can't replicate Earth, so our laboratory is not one in which we can control the variables. I think this is so critical for our students to really understand what makes geology so challenging, but also how the process of science can still occur through the use of modeling. Many of our students' understanding of models is limited to thinking of physical representations of objects (i.e., globes, science-fair-style volcanoes, etc…). They do not understand or recognize that models can be powerful tools for explaining and predicting (or "retrodicting" as is often the case in geology; Orion & Ault, 2007).

This becomes a critical aspect to the question of why we teach introductory geosciences to a non-major population. The more we can support our students with opportunities to explore the purpose and limitations of models through interpreting and using models to generate their own predictions, the more we can support our students ability to recognize the power of models. When they hear about models for climate change, volcanic eruption hazards, or risk-factors for different geoscientific phenomena, the more they may be willing to accept that a scientific model is our best way to explaining and predicting future phenomena. But just telling them isn't enough. Students need to EXPERIENCE working with models and it must be explicitly tied to the construct of models. It is extremely difficult for students to learn about any aspect of the process of science and impossible if it isn't made explicit (Lederman, 2007).

If we want our general education students to be "scientifically literate citizens," we need to seriously examine what is important to address in an introductory class, how we approach the topics and what is emphasized. In all of my introductory geoscience courses, I weave the process of geoscience as a common theme through which the mechanism of the content is taught. In my disasters class, I ask students to reflect on how each topic relates to the process of geoscience in specifically targeted reflections in the context of case studies (Kraft, 2012). In my physical geology class, I integrate the importance of modeling throughout the class (see the sample activity with this submission). In my historical geology class, I emphasize the process of retrodiction throughout the course. And yet with all of these approaches, learning gains toward understanding the process of geoscience is limited (van der Hoeven Kraft, in preparation). And yet any gains are critical since many of our introductory students are exposed to one or two science classes in college, and yet they make some of the decisions at a citizen level that may impact how we are able to accomplish geologic research.

Citations

Kraft, K.J., 2012, Encouraging students to think about how they think: In the Trenches, v. 2, p. 6-8.

Lederman, N.G., 2007, Nature of science: Past, present, and future, *in* Abell, S.K., and Lederman, N.G., eds., Handbook of Research on Science Education: New York, Routledge, p. 831-879.

Orion, N., and Ault, C.R., 2007, Learning Earth Sciences, *in* Abell, S.K., and Lederman, N.G., eds., Handbook of Research on Science Education: New York, Routledge, p. 653-687.

van der Hoeven Kraft, K. J. (In Preparation), Can students learn the process of science in an introductory geoscience course?

Should we teach how to cope with uncertainty and incomplete data?

Scott Linneman, Geology, Western Washington University

For many years I have introduced plate tectonic concepts to students using the Discovering Plate Boundaries exercise that Dale Sawyer developed (and many of us have amended). Despite a fair amount of simplification, the exercise still requires students to deal with real geologic data sets with real ambiguities and a lot of uncertainty. More 'novice' than any other, my pre-service elementary teachers find themselves baffled when they encounter gaps in the ocean floor age map or when they figure out that we don't know about all the mid-ocean ridge eruptions. How does the novice-to-expert transition happen that allows us to not be paralyzed by incomplete or messy data?

Maybe this comfort develops as we discover the historical nature of science. The fossil record is notoriously incomplete and this idea should be an outcome of every historical geology course. Or perhaps there are critical field trips that we all experience. The first personal encounter with a major unconformity seems to be an epiphany for most geo-students. "You mean we don't know what happened between the times that the schist was metamorphosed and when it was uplifted and exposed at the surface and when the sandstone was deposited?" I suggest that a personal encounter may be required, because I've seen the most elegant and well-presented lectures on the unconformities in the Grand Canyon not accomplish this conceptual leap. Putting your hand across an unconformity seems to evoke an emotional reaction about what we don't know about the deep history of the planet.

Ours is not a forward experimentation kind of science. We cannot construct planet scale experiments or even small scale experiments that take millennia to run (unless you want to alter the climate or biodiversity of ecosystems). The size, complexity and age of the earth systems mean we must rely on modeling. And models demand simplification.
I wish I had more time to develop this inquiry, but teach calls. I look forward to our discussions at the workshop.

Supporting Attachments

Geoscience by example

Ntungwa Maasha, Natural Science, College of Coastal Georgia

In June 2011 I was invited to the geology department of the Faulkner School of Engineering in the College of Science, University of Liberia to participate in revising its geology curriculum and to make the maiden presentation at the inauguration of its seminar program. It was the first time after two decades that I was going back to Liberia, where I lived and worked for ten years and had left hurriedly in the thick of a national crisis and did not even have a chance to wish farewell to anyone. For the intervening years the country experienced political instability, civil war, and the social chaos that thrives in such circumstances. At the time I received the invitation war and all political unrest had ceased. The country was on the mend, and civil institutions were back in operation.

Although my story on teaching geosciences began some thirty years ago when I took a teaching position in the Geology Department at the University of Liberia, I shall begin with some observations about my visit of the Geology Department in June 2011. From U.S.A my wife, son, and I arrived at dawn at Liberia's Roberts field International airport where Albert Chie, the chair of the Geology Department welcomed us, loaded our luggage into vehicles and brought us to Kendeja, a suburb of Monrovia, where he checked us into the plush resort there. He then assigned us a vehicle and driver for our transport during of the visit.

After breakfast the next morning the driver took us to the University campus where, after introductions, the Associate Dean of Engineering lead the geology faculty and other guest scientists in revising the department's mission and the curriculum. It is noteworthy that when I joined the University of Liberia as assistant professor of geology in 1978 I also took on administrative duties of the fledgling department that had up to then been under the guidance of Cletus Wotorson, Liberia's Minister of Lands, Mines, and Energy who had nursed the program into existence. The rest of the teaching faculty consisted of geologists from government agencies who taught there part time. Thanks to the wholehearted support of the University administration, within three years, the geology program had evolved into a full-fledged, degree granting department of five. As noted by several of those reviewing the curriculum the five members of the faculty collaborated to instill the best geological practices into the students. Weather in the classroom or in the field we were in agreement that giving example was the best way we would go. To this end we emphasized team work and open consultation among us for our students to emulate

The revision of the curriculum was a particularly insightful exercise for me. First, with the exception of only one, the first twenty graduates from the department had gone on to graduate school. It was most gratifying to know that invariably wherever they went for graduate school they were always deemed "well-prepared" or "over-prepared". Very telling indeed was the fact also during the time of the nation's crisis the department's alumni manned the Geology Department and it was the sole academic unit of the University of Liberia that functioned normally and continuously while other programs languished and were in shambles. Additionally, the Ministry of Land, Mines, and Energy, with most of its offices held by geologist trained in the department played a major role is stabilizing the country by superb management of its mineral and energy resources

Clearly, in a situation like Liberia where there was a large number of high school leavers competing for a few seats in the geology program at the university the chosen were ones who had scored highest on the university entrance examination and would probably succeed despite being taught by bumbling teachers. Besides, after half a dozen or more courses in four or five years interacting with a student how can one ever correctly attribute the cause of influence? Accordingly, that my former students had been very successful, or as my wife put it to them "prosperous" could very well be engendered by inspiration by teachers and colleagues or largely due to their own ingenuity and the wise use of the opportunities afforded them. Nonetheless I was impressed and amazed the most by how the spirit of cooperation pervaded their interactions and probably helped them to overcome unfavorable circumstances and to accomplish so much. For example, each of them had contributed to the mentoring of the students in the department of geology. Indeed the department flourished so that the annual graduation rate was around 20, while geology majors numbered well over 100, chaos in the country notwithstanding. In the initial development of the department, great emphasis was placed on field trips on weekends. In the present setting cooperation made it possible to raise the bar so that currently, each prospective graduate spends several months in apprenticeship with an industry during which he/she completes a substantial field project, writes a thesis on it, and presents it before the faculty. Amazing indeed!

I am deeply grateful to Albert Chie, chair, Department of Geology, University of Liberia for the invitation and making my visit to Liberia a possibility.

Supporting Attachments

Using Models in Geoscience

Robert MacKay, Clark College Physics and Meteorology

My geoscience career started over 30 years ago in solid earth geophysics, has touched on physical oceanography, and finally settled into atmospheric and climate change science. Much of my career has focused on science education; primarily teaching undergraduate physics and meteorology, and courses related to environmental modeling and Earth's climate.

Over the years my philosophy on science education has been highly influence by research in science education. Both the physics education and geoscience education research communities have influenced my approach to student learning. Student interest and satisfaction with the learning experience is always a top priority. As with most educators, sometimes we hit the sweet spot on this and sometimes not, but we always strive to get our students excited about the topic at hand. Another key element is the need to interactively engage students in a hands-on minds-on experience. Early in my teaching career I was introduced to the value of using computer simulation models to create active learning and inquiry base learning experiences for students. Although these sorts of activities are clearly not the only valuable interactive learning environments for students, they do appeal to my teaching style since much of my professional climate change research has been based on computer simulation models.

With this in mind, one method that I emphasize in my courses is how scientists use models to help them understand a system's past, present, and possible future behavior. One example student activity is a modeling activity designed to help students better understand the CO_2 problem. There first goal is to use a very user friendly online carbon cycle model (based on IPCC Bern Model) to estimate the carbon emissions over the past 50 years by obtaining a good fit between model and observations. To obtain good agreement between the model and observations of atmospheric CO_2 they adjust 3 parameters: 1) the initial 1960s CO_2 concentration; 2) the initial 1960 carbon emissions; and 3) the emission growth rate in percent per year. After this, they use their fit to explore possible atmospheric CO2 levels into the future based on different assumed emission scenarios such as: continue our present growth rate into the near future; accelerate this growth; or cut emissions growth rate. They also use the model to determine what cuts are required to keep CO_2 from exceeding some level like 450 ppm. Most students do a good job with this activity, are interested, and I hope are better prepared to critically read articles in popular publications related to this topic. It is often difficult to assess the lifelong impact of a particular learning experience since everyone assimilates information differently. The activity can be found at: http://www.atmosedu.com/physlets/GlobalPollution/CO2ModelAss2011.pdf .

In addition to learning about the strengths and limitations of models, my students are also introduced to key aspects of systems thinking while exploring different systems. It can be argued that a basic understanding of systems thinking should be included as a core learning objective for undergraduate colleges and universities.

Simulation environments created with computer simulation models are also easily transformed into a Game, either a solitaire game or a multiplayer game. My experience with using games for learning is limited but I have made several attempts, one of which is "The Energy Balance Game" at http://www.atmosedu.com/Geol390/physlets/GEBM/EBMGame.htm . I intend to explore the use of model-based games for student learning more in the future.

Over the past two years I have become increasingly involved in online instruction. Computer simulation and modeling environments are ideally suited for this mode of instruction. I've found that the instructions for online assignments must be very clear and detailed to avoid student confusion and frustration, and if they are not clear students are very quick to provide feedback. This extra demand for quality and continued student feedback has helped me greatly improve all of my assignments whether for online courses or face to face courses.

A Metacognitive Approach to Teaching Geologic Reasoning

Stephen J. Reynolds and Julia K. Johnson
School of Earth and Space Exploration
Arizona State University

Solving geologic problems requires various reasoning strategies, some of which are unique to the geosciences. Most geologic problems involve observing, interpreting, and trying to make sense of a complex array of features, such as various geologic structures in an outcrop or diverse geologic units in a landscape. From such observations, geologists try to characterize the most important features, interpret the order in which the features formed, and derive the underlying processes that were involved. Here, we provide a metacognitive perspective on teaching students how to improve their geologic reasoning in understanding landscapes and other geologic systems.

Metacognition is commonly described as thinking about thinking, or knowing about knowing. It involves a self-awareness and self-assessment while reasoning about some problem. A main goal of a college education, whether for scientists or non-scientists, is to improve critical thinking and reasoning strategies about problems relevant to society. We suggest that explicitly incorporating some metacognitive approaches in teaching geology in the classroom and field can help us achieve these important scientific literacy goals.

One of the main strategies in raising metacognitive awareness is to explicitly model geologic problem solving in front of students. A key component of this modeling process is to share the instructor's thoughts during a problem-solving activity by the use of a think-aloud approach. For example, in teaching students how to observe landscapes, the instructor shares aloud with students all the aspects that the instructor observes, identifying which aspects are important and which ones are not, for the particular context being considered. The instructor notes which observations and interpretations are more certain and which ones are less certain, what information remains unknown, and what types of data would be needed to fully define the setting and to reconstruct the processes and sequence of events that resulted in the scene. In an introductory geology class, this involves spending one or more class periods examining landscapes and modeling for the students how to observe and interpret the key aspects. The same approach can be used while presenting information about other geologic systems, such as features and processes associated with plate boundaries, or outcrops in the field. When introducing students to a new field area in a field geology class, we typically walk around with the students sharing everything that we see and think about for various features we encounter, sharing our thoughts about possible strategies for approaching different problems and predicting where we would go in the field area to better constrain the geology. The advantage for students of this think-aloud, metacognitive approach is that they can begin to appreciate the diverse thoughts, types of data, and various strategies that will enable them to solve geologic problems. The advantage for instructors is identifying all the strategies and wealth of background knowledge we use in problem solving, some of which are so automated that we may not recognize we are using them, and so we may never share this knowledge and strategies with students.

One result of a think-aloud metacognitive approach is that it helps students with what we consider to be one of the most essential skills for a geologist – disembedding. Disembedding involves being able to extract essential information from a complex visual display, in other words to distinguish the signal from the noise. It comes into play in nearly all geologic situations, such as identifying key geologic structures in an outcrop obscured by loose materials, rock varnish and stains, plants, and other distracting elements. Disembedding is important in observing a landscape and recognizing that it consists of a relatively limited number of geologic features, including layers, joints, bedrock, and talus. Instruction on disembedding can be done in person in front of the class or by means of overlays and other signaling techniques.

Another approach commonly recommended for improving metacognitive skills is to have students make a graphic representation of their thoughts to explicitly identify the knowns and unknowns, the influence of different variables, and the relationships among different aspects. In the geosciences, the most spatial of the sciences, concept sketches are an ideally suited graphical learning tool for promoting metacognition. A concept sketch is a relatively simple sketch annotated by complete sentences that describe the features, processes, and relationships among different features and between features and processes. The starting point for a concept sketch can be a photograph of a landscape, textbook-style illustration, map, animation, or observation of a natural scene out in the field. Constructing a concept sketch requires us to identify which aspects in the visual display are critical for understanding and which ones are not, that is, to be able to disembed. We have to decide which aspects of the figure to sketch and how to best show these aspects. We must decide how to explain the geologic system in our own words. This process requires us to engage in metacognition as we decide what we know and what we do not know. It also requires that we develop a strong linkage between visual and verbal knowledge, an activity that promotes deeper learning. We have strong evidence that having students construct concept sketches results in a much deeper understanding of geologic concepts than nearly any other educational activity we have identified.

In order to free up time in class for explicit instruction on metacognitive strategies, the instructor will not be able to cover as much content as is typical. This is an acceptable trade-off since one of the main goals of every geology instructor is to teach critical thinking and problem-solving skills. If an instructor deems this goal important, then it is appropriate to spend sufficient time in the classroom achieving this goal. If content not covered in class is critical, it will have to be learned outside of the classroom. To encourage such outside-classroom learning, we recommend the use of a what-to-know list that identifies what information and skills students are expected to understand and be able to use, even if that topic is never discussed in class. This list should be handed out before such material is taught and before students encounter that material in a textbook. We also recommend that curricular material feature a high degree of integration of text and figures, like a figure surrounded by accompanying text, perhaps with leaders that point to the part of the figure being described by the text. Cognitive and educational research demonstrates that students retain more information and can better use information from integrated text and figures than from long blocks of text that are not proximal to, and are only loosely linked to, accompanying figures. With appropriate materials from which students can learn on their own – and making students responsible for learning some content outside of the classroom – an instructor can spend time in classroom using metacognitive approaches to help students become more self-aware, self-assessing, and self-regulating problem solvers.

Developing a Hands-On Approach to Collecting, Analyzing, and Interpreting Weather Observations and Climate Data

By Cindy Shellito

Meteorologists and climatologists spend most of their time sorting through vast quantities of data – data from observations and numerical modeling. A suite of numerical codes is used to create stunning visual images of the data and model output. However, the enormity of the data, and the complexity of the tools used to sort, view, and analyze this data are overwhelming to most students. The tools of the trade are abstract (no rock hammers!) and students find it hard to conceptualize what goes on in a computer in the processing and analysis of data. Not only are the tools of the trade daunting, but students have preconceptions about the nature of science that make teaching about these tools a challenging prospect. Many students have had the idea that science is of a 'bunch of facts,' and that science involves looking at things dispassionately, without creativity.

In my courses, I try to present students with activities and assignments that will introduce them, very gradually, to methods of observation and numerical analysis, and also challenge their preconceptions regarding the nature of science. To begin to conceptualize what data really means, I've found that this must involve a 'hands-on' approach. At all levels, from introductory to graduate courses, there are basically three means by which I introduce students to methods used in meteorology and climatology: (1) in-class activities that require students to analyze or interpret data, (2) term research projects that require students to pose a question, gather or examine data, make observations or conduct an experiment, and draw conclusions, and (3) discussion and evaluation of research articles in scholarly journals.

When I first began teaching introductory meteorology, I developed an assignment that I hoped would give students some hands-on experience in weather observation and provide them some insight into the nature of scientific observation. I required my students to construct a weather instrument (such as a thermometer, barometer, hygrometer, or anemometer) from household materials and observe changes in weather over five days. The assignment has evolved somewhat over the years, and now I also require students to create a numerical scale and calibrate their instrument. This provides them with an opportunity to work with data, and a quantitative way to evaluate the performance of their instrument. Also, after constructing their instruments, students bring them to lab class, where they consult with others who have built the same type of instrument. Here, they share their frustrations, problems, and ideas for improving the instrument and their observations. Students submit a journal of their activities at the end of the semester, along with an overall evaluation of the performance of their instrument.

Students often comment to me how much they enjoy this assignment. They enjoy the fact that it requires them to get outdoors, and use their creativity and ingenuity. They often seem amazed that they can build something, on little or no budget, that will quantify changes in the atmosphere. They also learn how difficult it is to create an instrument that measures something consistently. They realize that sometimes there is more than one way to build an instrument, and that design considerations will tie in closely with consistency and accuracy of their instruments. They learn about the nature of uncertainty when they conduct an analysis of their data, and they learn about the value of sharing ideas with their peers to improve the design of their instrument. This assignment requires students to integrate things they have learned in lecture and lab, and apply it in a new way, and for that, I have been really happy with it.

In my upper division courses, I teach students who are majoring in meteorology and environmental science. In order to best prepare for the job market, these students must become familiar with handling larger quantities of data. As a climate modeler, most of my emphasis in these courses is on using numerical models to provide insight regarding factors that affect climate. I begin by introducing students to the simplest of numerical models first. I usually have them conduct a short, in-class 'research' project using Excel spreadsheet to calculate global temperature based on variations in climate forcing parameters. In my Paleoclimatology course, this practice with Excel leads into a term project where they must either use a simple numerical climate model or complete an analysis and comparison of climate data available online (e.g., comparing two data sets, or two different types of proxy data). In an upper division Climatology course, students must complete a full research project investigating some aspect of the climate system with a low-resolution 3-D global climate model. Students are sometimes overwhelmed by both the limitations of the model, and at the same time, by the enormity of model output, but they learn to focus their model analysis on the parameters that will provide the best answer to their question.

I've had alumni tell me that they have used some of the computational skills in their work. Students who go on to become teachers have adapted some of my assignments in their classes. Through these assignments and projects, my goal has been to encourage students to develop skills that will be applicable in many different types of work environments. While I realize that the content of my courses in important, I hope to instill in my students a way of scientific thinking and problem solving that will last a lifetime.

Learning Geoscience by Talking and Doing

Julie Stoughton, Natural Resources and Environmental Science, University of Nevada Reno

I began my teaching career over twenty years ago as an outdoor educator at Yosemite Institute in Yosemite National Park. I had massive granite formations, beautiful rivers and towering trees all around me for teaching students about the connections that link us to our planet, and the science behind these connections.

After three years of sharing the wonders of Yosemite with students ages 10 to 18, I wanted to try science myself. I completed my masters degree in earth science with a focus on biogeography at Montana State University. I immersed myself in studying the effects of legacy mining on ecosystems outside Yellowstone National Park, and learned a great deal about how science works. Although I enjoyed doing science, I realized my career passion was teaching science, so I transitioned to teaching high school science in an urban California setting.

Fast forward several years, and I now teach natural resources and environmental science to freshmen and sophomores at the University of Nevada Reno. My position includes teaching a core non-science majors course (Humans and the Environment) every semester, an introductory course for Natural Resources and Environmental Science (NRES) majors every fall, and assisting with a course where junior and senior science majors teach science lessons in elementary schools every spring. I also advise the majority of our freshmen, sophomore and transfer NRES majors (Ecohydrology, Environmental Science, Forest Management and Ecology, and Wildlife Ecology and Conservation).

In order to use geoscience methods (such as data analysis, data interpretation, observation, spatial and temporal awareness) students need practice and familiarity with basic geoscience concepts. Although I now teach lecture classes in big rooms rather than teaching outdoors with small groups, I engage students with opportunities to talk about science and do science. I find that the traditional lecture format of "sage on the stage" is not the best approach for improving student learning, particularly for entry-level undergraduates. My non-majors students often dislike or fear science, and even my new majors lack science experience and knowledge. I create a classroom environment where students can share and practice ideas to improve their knowledge and abilities.

At the start of each semester I assign students to a small group of 4 or 5 individuals. The students sit close to each other for the semester, and communicate during in-class discussions. This small step increases the comfort level as students come to know a few other individuals in the class. Now we can review concepts in class, discuss scientific ideas or interpret graphs and data. For example, students often struggle with biogeochemical cycles. As I present the basic components of the carbon cycle, I pause and put review questions on the screen for small group discussion. After describing EPA criteria air pollutants I direct small groups to quiz each other on the names and characteristics of each pollutant. If I have an important graph about energy sources I put questions alongside the graph and ask groups to discuss and write down their answers. I often use "pair-share" discussions during review questions to improve student learning.

Once my students are talking about science, I add doing science to the agenda. Again, I start at a very basic level that meets the needs of my students. Before we begin doing science in labs, we "do" science concepts in class. Because geoscience includes large picture conceptual thinking I start with conceptual diagrams in lecture. I typically give handouts with a key science concept diagram or graph that is missing labels or data. As we discuss a concept in class, students add notes and labels or data to the handout. This step helps students internalize concepts. For example, as we discuss layers of the atmosphere I describe temperature variation with altitude. Rather than simply showing the graph I give students a copy of the graph axes. I put data on the screen and students plot the points. Then students label the atmospheric layers by referring back to their notes. During a discussion on aquatic food webs I hand each group a predator/prey data sheet. Students sketch the food web using the data and a previous example to guide them.

My vision for students doing geoscience extends to our labs and fieldtrips. There are four lab experiences for my non-majors course and one full day fieldtrip for my introductory majors course. Both the labs and fieldtrip are designed so students can do science and connect the science to a local context. For example, the four non-majors labs all link to our local Truckee River watershed. Students begin by studying landscape patterns on a watershed map, then practice collecting transect data in a riparian area. They identify aquatic macroinvertebrates from the Truckee River and test water quality. As they gather and interpret data, then write about their findings, they see the connection between their local environment and how scientists gather and convey information.

In my experience, students learn to appreciate and enjoy geoscience as they talk and do science, both in the classroom and in labs. By the end of each semester I hope my non-majors students have a greater understanding of the science concepts and a greater willingness to engage with data and discuss scientific ideas. I hope my introductory majors have some basic science concepts and tools for moving on to their subsequent science classes.

The Development of my Understanding of the Methods of Inquiry in the Earth Science

Jeff Thomas

My first job after college was working for a small, private weather firm. One of my responsibilities was organizing community outreach programs such as teaching elementary and middle students about the weather. During these programs, I conducted short, high-interest weather demonstrations with students such as making "tornados" and "lightning." Based on students' enthusiasm during these demonstrations, this was the method of teaching I thought science ought to be taught.

A few years later, I obtained my teacher certification to teach secondary earth science. Similar to the outreach programs, my method of teaching was limited to lecturing from the textbook and implementing traditional lab activities (e.g. cook-book labs, demonstrations). Students seemed satisfied. My principal, however, encouraged me to embed student-centered inquiry-based labs as part of my instruction—a "new" instructional method that I was unfamiliar with. She encouraged me to do this because these "new" labs were similar to the ones that the tenth-grade students would now complete for the state's new science assessment.

As part of this changing emphasis, I also learned about these student-centered inquiry-based labs from the state's new teacher induction program. I learned that inquiry required students to identify a related set of variables to test (e.g. independent and dependent variables), pose testable questions, develop valid procedures, collect quantitative evidence, and draw evidence-based conclusions. This was the experimental method of doing science. Since I was previously unfamiliar with "inquiry," this process was how I began to develop my understanding.

Although I do not recall the exact content of the first inquiry-based lab that I gave to students, I certainly remember implementing it. This was because students did not understand the goal of the lab or what to do. For instance, they did not know how to identify a variable and they did not know how to write a problem. Worse, I did not know how to guide my students. As a result, the lab was a disaster. Since I worked for a high-achieving district, I knew I had to figure out a better way to implement these inquiry-based labs. So, I spent the next several years trying to figure out how to scaffold these labs for my students.

During my first five years of teaching secondary earth science, I continued to develop my pedagogical content knowledge of inquiry. I taught my students how to do this experimental method of inquiry. Over time, my students were more successful doing these kinds of labs. In fact, the majority of them were able to identify a related set of variables to test, pose a testable problem, and draw evidence-based conclusions.

As I developed my confidence to teach this method of inquiry, I began to think more deeply about the different kinds of methods earth scientists use to conduct their own investigations. I also thought about the scientific practices that I employed as a meteorologist. To forecast the weather, for instance, I collected and analyzed past and present weather data as well as various computer forecasting models. Based on this evidence, I then developed a forecast. At times, I questioned if what I was doing was “inquiry” because it did not seem align with experimental method of doing inquiry. I felt this way because this experimental method was expected to be implemented with students (e.g. the state science assessment). This view was reinforced by some of my science colleagues too. They viewed earth science as a descriptive science wherein students made simple “observations” of the world such as identifying sun spots or differentiating between an igneous rock and a metamorphic one. Thus, the methods inquiry in the earth sciences was limited to students observing the world around them.

Over time, I began to appreciate the differences and similarities between the experimental method of inquiry and with the alternative methods of inquiry used to study the earth systems. I realized that understanding the factors that affect the erosion of a stream (e.g. experimental method) was just as important as studying the dynamics of an entire watershed (e.g. systems thinking). In either case, there were three common elements of inquiry: research questions, evidence, and conclusions. I also realized was that making detailed observations as well as developing and experimenting with models to understand the earth’s natural systems, both spatially and temporally, was also a valid method of inquiry.

Thus, I embedded new types of inquiry-based instructional activities in order to develop my students’ understanding of the earth systems. One of the first challenging lessons I had my students do was an activity called “Discovering Plate Boundaries” by Dale Sawyer. In this activity, students were given four data-based maps that depicted earthquakes, volcanoes, topography, and the age of the ocean floor. In essence, students classified different kinds of plate boundaries based on the data they observed and analyzed—similar, yet more simplistic, way scientists began to develop the theory of plate tectonics.

Another strategy that I employed was using online real-world data to teach weather concepts with my high school meteorology class. Most of the course used current and past weather data to inquire and understand major meteorological topics such as diurnal cycle, seasons, and high and low pressure systems. One activity I did with my students was “The Reasons for the Seasons,” which was an activity I recently published in the *Science Teacher*. In this activity, students predicted the mean average high temperature for five cities along the east coast of the United States and then compared their predictions with data they collected from the Northeast Regional Climate Center at Cornell University. Based on their analysis, students’ hypothesized factors might contribute the seasonal differences among these cities such as distance from the sun, the amount of daylight hours, and the angle of the sun’s energy striking the surface of the earth. Students then collected data, from multiple online data sources, to confirm or reject their hypotheses.

After 11 years as a secondary earth science teacher, I now teach science methods and a few introductory science courses. For all of my courses, students conduct investigations that utilize multiple methods of inquiry. My students, for example, still do Dale Sawyer’s Discovering Plate Boundaries activity—an inductive method of inquiry that focuses on spatial reasoning. Similar to my high school students, they too, need scaffolding to help guide them through the inquiry process.

Overall, the progression of my understanding the methods of inquiry has evolved from naïve (e.g. cook-book labs, demonstrations), to narrow (e.g. experimental), to broadening conceptions (e.g. systems thinking). I look forward to developing instructional strategies to engage all students in the methods of geoscience.

What should all citizens know about geoscience?

Basil Tikoff, Geoscience, Univeristy of Wisconsin - Madison

The problem

I'll just put it out there: The way we teach science at the introductory level is doesn't work.

For the last 100 years, we have known that there is a fundamental problem with teaching science, specifically to non-scientists. Despite the fact that US universities have been the world leaders in scientific discoveries, the science community has failed to provide citizens with a foundation of scientific literacy. Belief in pseudoscience, rejection of scientific theories and claims (evolution, human-induced climate change), and lack of understanding of ongoing scientific research (such as the significance of peer review) are widespread among the general population and college graduates. The decline in science understanding in the US population has been documented in a variety of ways, most vividly in the "Rising above the Gathering Storm" report by the National Academy of Sciences. Despite the clear indications that we live in a scientific age – including the internet and global communications – most people do not embrace, or even understand, basic scientific attitudes and worldviews. They are turned off by how it is taught, and they end up carrying a distaste of science for the rest of their lives (Seymour, Elaine and Hewitt, Nancy, Talking About Leaving, Why Undergraduates Leave the Sciences, 1997).

Even students majoring in science and engineering fields continue to be frustrated in overwhelming numbers by the substance and approach of these introductory courses. They report (among other things) curricula that are "overstuffed with material and delivered at too fast a pace for comprehension, reflection, application or retention." (Seymour, Elaine, "Testimony before the Research Subcommittee on the Committee on Science of the U.S. House of Representatives, Hearing on Undergraduate Science, Math, and Engineering Education: What's Working?" March 14, 2006.) What most students learn from an introductory class – including some of our best students – is that they don't want to study science. If students with a self-professed aptitude for science struggle with typical undergraduate science teaching, it is not surprising that our courses fail dramatically to meet the needs of non-science majors, i.e., those studying business, law, nursing, and education or with majors in the humanities or social sciences.

Even if a specific class was done superbly with the best teaching practices, there is still a structural problem with the entire organization of introductory courses. Introductory courses teach material that is isolated by discipline. Chemists teach chemistry, botanists teach botany, and – of course – geologists teach geology. Our students, however, need to know more broadly about a variety of different subjects and how they relate to each other. The disciplinary structure of the university — departments operating in silos isolated from one another — is a significant impediment to holistic learning, especially for our non-science majors.

Yet it is essential that students know some aspects of the geological sciences: This will be the century of the geological sciences. The reality (and ominous threat) of climate change, decreasing material resources, increasing demands for fresh water, and a host of other issues will be essential to understand for any citizen of a democracy. This is major and urgent challenge for us, now.

A possible step forward

While there are many ways to deal with this problem, this is the approach that I've been working on with colleagues at the University of Wisconsin-Madison. We are proposing a three-part introductory science sequence (the "Science Illuminated" series). These courses are: (1) Deciphering the Past; (2) Investigating the Present; and (3) Predicting the future. A major conceptual breakthrough in conceptualizing these courses was the integration of physical, biological, and earth science in each class. The educational philosophy of courses is straightforward: Learning about the methods of scientific knowledge production across disciplines is more relevant to future citizens than the particular subject matter of any one discipline. Each class focuses on how science is done, not on memorization of disciplinary knowledge.

These courses will enable students to function as informed citizens in an increasingly scientific world by: 1) Engaging in the practice of science and understanding the construction of scientific knowledge; 2) Understanding and using scientific reasoning; 3) Assessing, applying, and communicating science knowledge; and 4) Clearly distinguishing between science and non-science, and articulating the difference. The emphasis will be on hands-on activities that relate directly to how science is done.

Relevance to this workshop

The big question that this approach requires answering is this: What should all citizens know about geoscience? The answer probably needs to be split into: 1) Content objectives; and 2) Methodology objectives. I have a hard timing breaking away from my own training; I do think it is necessary that we teach some content objectives. I think, for example, people should know that the earth is 4.6 billion years old, life has been around since ~3.5 billion years and life-as-we-know it has been around since the Cambrian, plate tectonic describes the first-order deformation of the earth (and explains most earthquakes), and what is the water cycle (where is fresh water from and why is it so precious). But, really, the methodological approach is far more important.

It turns out that any field that is studying the past uses the same "bag of tricks". There are, as I can determine, only really three ways to determine the natural history: 1) space-for-time substitutions, 2) radioactive "clocks", and 3) historical records. Astronomers do it, Evolutionary Biologists do it, and – of course – geologists do it. Moreover, the data for astronomers, biologists, and geologists is mostly based on observation of a natural system without the ability to manipulate it (how can you manipulate a star?). None of these scientific disciplines heavily employs "the scientific method" that is taught in high school, which exclusively involves experimentation. There is more than one methodological viewpoint that scientists use to address problems.

Bill Bryson to the rescue

I can't say things as well as Bill Bryson (my apologies for those who find him irritating, but I really like his writing). But, he really gives a good justification for why you would want to study methodology of science. So, here is a heavily edited passage from his introduction to the book *A short history of nearly everything*.

> "My own starting point, for what it's worth, was an illustrated science book that I had as a classroom text when I was in fourth or fifth grade. The book was a standard-issue 1950s schoolbook - battered, unloved, grimly hefty - but near the front it had an illustration that just captivated me: a cutaway diagram showing the Earth as it would look if you cut into the planet with a large knife and carefully withdrew a wedge representing a quarter of its bulk.
>
> "It's hard to believe that there was ever a time when I had not seen such an illustration before, but evidently I had not for I clearly remember being transfixed. I suspect, in honesty, my initial interest was based on a private image of steams of unsuspecting eastbound motorists in the American plains states plunging over the edge of a sudden 4,000 mile high cliff running between central American and the North Pole, but gradually my attention did turn in a more scholarly manner to the scientific import of the realization that the Earth consisted of discrete layers ending in the center with a glowing sphere of iron and nickel, which was as hot as the surface of the Sun.
>
> "Excited, I took the book home that night and opened it before dinner - an action that prompted my mother to feel my forehead and ask if I was all right - and, starting with the first page, I read...
>
> "...And here's the thing. It wasn't exciting at all. It wasn't altogether comprehensible. Above all, it didn't answer any of the questions that the illustration stirred up in a normal inquiring mind: How did we end up with a Sun in the middle of planet? And if it is burning away down there, why isn't the ground under our feet hot to the touch? ... And how do you know this? How did you figure it out?"

So – there is it. We need to engage the young Brysons of the world, if we have any chance of living sustainably on this planet. The answer, as he points on, is on methodology and – in his own example – is geological. We just need to meet these students were they are and I think methodology might be the key.

Supporting Attachments

Why I have my students explore methods of the geosciences

By Paul Vincent

Valdosta State University

Over the past several years I have taught a course that has the title: Tools of the Geosciences. This is a course that all geoscience major take at my institution during the fall of their sophomore or junior year. After they take this class, the students begin a three semester thesis sequence. The principle thrust of the class is to orient the students to studies in and about the geosciences. They are given a broad background in many aspects of geoscience in an attempt to start them thinking about their thesis project. They get a little bit of everything in this class. Topics covered in the semester include a basic definition of the geosciences, field measurement methodologies, computer techniques, and library research methods.

When I get these students they are often brand new to the program. They have probably found their way into the major via our general education courses in Physical Geology or Environmental Hazards. The find the topics interesting, have a propensity for science but very little knowledge about geoscience. Because I want to give these students a broad overview of geoscience, I take something of a mile-wide-inch-deep-approach. Even though I have a limited amount of time to spend on each of the topics on my syllabus, I have found that the students develop a greater understanding if I do not lecture on some topics even though it could be accomplished in much less time. Instead, I allow the students to grapple with certain assignments without specific directions. It really annoys the students when I don't tell them outright what they need to do. Of course the pay-off for the student is they play a larger role in the development of their own understanding of the new concept or technique. If I were to simply tell them, they would not find it nearly so meaningful.

For example, in the activity that I am submitting for this workshop (measurement of a quarter acre), I refuse to tell the students how to use the tape measure to most accurately delineate their square of land. Quite often the students anticipate the assignment will be very simple; after all, how hard can it be to measure a square? Frustration sets in quickly because they simply don't realize just how hard it is to measure straight lines that intersect at 90 degrees over a longer distance. It becomes even more frustrating to them that I will not tell them what they need to do to get a good square. I will also point out how flexible the tape measure can be and pulling too hard the distance can be distorted. The end result is the students really have to think on their own. At some point, realization sets in and the students figure out what needs to be done all by themselves.

So, basically, my approach is not to "teach" particular methods of geoscience. I am happy to be a resource for the students and give them guidance. Ultimately, however, they discover what they need to know on their own. Such a discovery makes that knowledge all the more meaningful.

Enjoy making observations and being frustrated? If you answered "yes", a career in geoscience is for you!

Becca Walker

Geologists observe and interpret. Observe and interpret. Observe and interpret. In my teaching at a large, urban community college, I find myself repeating this phrase over and over in the classroom, in the field, and in the context of assignments. Although I encounter a handful of science majors in the introductory-level courses that I teach, the majority of my students are non-science majors who enroll in my courses to satisfy a general education requirement. For a variety of reasons, including promoting scientific literacy; reducing misconceptions about how the scientific process works; and providing potential geoscience majors with an accurate portrayal of what geoscientists do; conveying the nature of geoscience research and "how we know what we know" is an important part of my curriculum. Below, I've provided three examples of my approach to teaching the methods of geoscience.

Geoscience method #1: Observing and interpreting

It took me roughly two years of teaching to realize that most of my students struggle to distinguish observations from interpretations. This distinction is so crucial in understanding how to think like a geologist that "observations and interpretations" is a recurring theme in all of my courses. For example, my physical geology class begins with a non-geologic photo (usually an embarrassing photo of me) and a request for observations. Many students offer interpretations at this stage, so a discussion of observations vs. interpretations ensues. Once they understand the difference between the data and the story using a non-geologic example, we move on to talk about how detailed small and large-scale observations allow geoscientists to unravel a geologic history.

The culmination of their work with observations and interpretations is in the field. Prior to their field trip, students in most of my courses analyze an outcrop during class with the help of a YouTube video on outcrop analysis, a color photo of an outcrop and a representative hand sample, and a hypothetical example of a field notebook entry that I provide. Ideally, they are comfortable with the "observe and interpret" procedure before going out in the field. Once we get to the field area, I add one extra step: sketching. In my experience, giving students time to make detailed, labeled sketches, think about the significance of what they are observing and sketching, and later, making sure that every label (observation) is tied to an interpretation is hugely beneficial.

Geoscience method #2: Evaluating multiple lines of evidence to identify patterns

How do geoscientists forecast volcanic eruptions? Which oceanographic data were used to support the idea that plates move? How do geologists recognize faults in the field? Our understanding of the Earth system comes from identifying patterns, and although this is a fundamental concept that I address verbally with my students, I believe that the best way to illustrate this geoscience method is to have students discover the patterns for themselves. So far, the most effective way that I have found to accomplish this self-directed pattern recognition is a variation on the jigsaw method. For example, the activity that I have contributed to the resource collection for this workshop is a short in-class exercise on the lines of evidence for plate tectonics, a concept about which we have not talked, nor even named. Briefly, each student is given either an A, B, or C preparation exercise with instructions. The A prep asks students to read and prepare to discuss the "continental shapes" aspect of continental drift and observe a map showing the age of the oceanic crust. The B prep asks students to read and prepare to discuss the “rocks and fossils” aspect of continental drift and observe a marine sediment thickness map. The C prep asks students to read and prepare to discuss the “glacial deposits” aspect of continental drift and study figures of physiographic features of the ocean floor. During the next class meeting, students break into groups of 3 with an A representative, B representative, and C representative. Together, they look for patterns among their data and come up with some ideas about why they observed the patterns. It’s an effective, non-lecture introduction to plate tectonics, gets them thinking about how the idea was developed, and provides practice with looking at multiple data sets simultaneously.

Geoscience method #3: Not knowing what you will find before you find it

The geologic history of the Earth is a story, and one of the principal challenges that I face in teaching the methods of geoscience is conveying to my students that at the onset of a geoscience research endeavor, scientists don’t know where the story is going. In class discussions and conversations, I consistently encounter the misconception that real science is neat and linear, starts with a hypothesis and ends with a conclusion (with a cookbook experiment and some perfectly reproducible data in between), and that somehow, the scientist knows what his/her results will be before doing the work. This view of the scientific process is an inaccurate depiction of the iterative and dynamic nature of our understanding of Earth processes, and it is a misconception that I work hard to address in all of my courses.

This idea about the methods of geoscience was plainly evident this semester when a colleague and I began supervising 8 of our students on an independent study project. The students on this team have taken close to all, if not all, of the courses that we offer in our department. They were ready for a challenge. Together, we came up with a skeleton for a project investigating changes in channel shape and sediment characteristics of a fluvial system in Orange County between its source and the beach. I can’t think of another time in my career when I have seen so many jaws drop as I have over the course of this project. Most of these dropped jaws have been related to the realization that the professors don’t have the “right answer”. Some examples:

1) *[The first recon day. Students and professors stand in Trabuco Creek, observing the stream channel.]*
Professor: What are some of the characteristics of this channel that you want to measure?
Students: Well, what should we measure?
Professor: I’m not sure, that’s why I’m asking you.
[Students’ jaws drop. End scene.]

2) *[A couple of weeks into the project. Student and professors meet in a faculty office.]*
Student: We have three stream profiles done from different locations and have taken sediment samples at the sites.
Professor: Great. Did you see any differences in your profiles?
Student: Yes.
Professor: Then the next step is to think about what these differences are telling you geologically.
Student: What they’re telling me?
[Student’s jaw drops. End scene.]

I met with the independent study team today and watched them continue to chew on identifying their objectives for their next trip to the study area. They wanted me to tell them what their focus “should” be. I shrugged my shoulders and asked them what they thought was most important, based on the geology they had observed in prior trips to the field area. I was incredibly proud when, instead of their jaws dropping, they gave me a list of ideas. They are learning one of the most important geoscience methods: establishing a plan for observing and collecting data in the face of uncertainty.

Challenges of preparing teachers in all grade levels to teach science

Kandi Wojtysiak

Rio Salado College in Tempe, Arizona promotes an innovative program in teacher education. The education department is faced with many challenges and one is ensuring our new teachers have the resources and training to teach science effectively. Our teacher prep program is an online program with in-person components. Students learn practical application of science teaching methodology and curriculum design. The techniques of hands-on science and science as inquiry are taught.

Once our pre-service student educators graduate and are in the classroom, they need to put theory into practice in a world where high stakes testing of other subject matter is the primary focus. Additionally teachers are faced with a pacing guide and breadth is favored over depth. In a direct instruction classroom, more concepts can be "covered" in a shorter amount of time. When science is taught as a static discipline, few students develop an interest in science. Science needs to be taught as relevant and dynamic. We need to develop our teachers to teach science n engaging ways. The inquiry method is highly favored over direct instruction. In a recent study by WestEd in California, it was discovered the vast majority of California middle school students are being taught science by content reading and not by the use of meaningful experiments.

As professional educators, we need to teach our pre-service teachers the value of hands-on experiences as well as the dynamic field of geoscience. Geosciences are relevant and can be taught in an engaging way. Geosciences demonstrate how to apply the science processes. Geosciences Students can learn how the different disciplines connect. The study of engineering connects to geology and many other fields in science. The field of Geosciences is growing rapidly and teachers need to understand the importance in context of those they teach. Our future educators must be able to teach their young students, they are the problem solvers of tomorrow and scientists are the great problem solvers of the world. As STEM becomes increasingly important and the integration of these topics is more crucial, teachers need to be aware of the methods and the ability to integrate. As an instructor of pre-service teachers I need to inspire these future educators and teach them the importance of these instructional methods. My student must feel capable and confident and be ready and willing to teach science as a meaningful experience.

Robelen, E., (2012, March 23), *Study Finds Middle School Science Instruction Lacking in California*., Retrieved from http://blogs.edweek.org/edweek/curriculum/2012/03/most_california_middle_schoole.html