Integration of Geoscience into Geothermal Bore Field Design

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Today's technological advancements play an important role in the way our society gathers and disseminates information amongst itself. As educators, we must be creative in both our pedagogy and how we integrate content from various disciplines into our courses. Once students enter the workforce they will be challenged to function within multidisciplinary teams to solve real world problems. This specifically holds true for the engineering and geoscience disciplines.

Within civil and environmental engineering it is easy to see how geoscience correlates. However, in mechanical engineering, there are a few distinctly different correlations taking place with geoscience. These primarily reside in the area of heat transfer and energy generation. The engineering courses I teach in heating, ventilation, and air conditioning (HVAC) introduce the topic of ground-source heat pumps. These systems utilize geothermal energy in the form of heat transfer to or from the earth through a liquid. The heat transfer takes place in either open or closed loop systems both affecting the natural state of the soil. When engineers design this type of renewable energy system they need to be able to understand the geology of the soil they are dealing with and how its properties affect the performance of the system. Currently my students utilize soil classification tables and design standards published by the International Ground-Source Heat Pump Association (IGSHPA) to estimate the amount of energy that can be transferred through a geothermal bore. In order to gain a better understanding of how to read well logs and interpret formation thermal conductivity tests, engineers must have a greater understanding of geoscience.

One of the approaches I have tried with my students is having a civil engineering professional guest lecture about well logs and how drillings are classified. This approach only provided a limited amount of exposure to geoscience and how it integrates with engineering. As geothermal heat exchange becomes more widely used as a renewable energy source engineers need to have a greater understanding of geoscience. Through this expanded knowledge engineers will have the skills needed to generate good bore field designs that meet their project's heating and cooling demands. If engineers do not adequately understand geoscience there is a good chance they will either oversize a bore field causing unneeded drilling costs or undersize the bore field resulting in not enough heating or cooling for the application.

To strengthen the integration of geoscience into my engineering curriculum I plan on working closely with our earth science and land resource department to develop content both for lecture and laboratory instruction. I propose introducing students to the various drilling processes and how well logs are developed based on these different methods. Students will learn how to generate a well log and classify the drillings in a laboratory environment. Through hands-on learning the students will gain a deeper understanding of the drilling processes available and how to generate and interpret their well logs. The desired outcome from this experience is intended to increase the students' knowledge needed to design and size geothermal bore fields.

Integrating Engineering and Geoscience Through Technical Writing

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Well prepared engineering students must understand the context in which they apply their knowledge and skills. In particular, all flavors of future engineers (from computer to civil, and everything in between) will need to incorporate sustainability principles and practices into their designs and workplaces. At San José State University (SJSU) we have been combining study of earth and the environment with technical writing for almost 10 years. The engineering technical writing course (Engr 100w), described in detail in Linsdell and Anagnos (2011), was designed to prepare students for today's global engineering environment while also meeting SJSU general education goals. The course defines several learning outcomes related to improving communication skills, but it also includes the following three outcomes related earth and the environment:

- Students should be able to demonstrate an understanding of the methods and limits of scientific investigation.
- Students should be able to distinguish science from pseudo-science.
- Students should be able to apply a scientific approach to answer questions about the earth and environment.

Nearly all ENGR 100w writing assignments are focused on issues related to the environment. This is accomplished by hosting industry experts and academic researchers to present seminars on relevant environmental topics, and then assigning weekly written assignments related to the talks. Typical topics might include climate change, alternative energy, sustainable construction or manufacturing, ocean monitoring, earthquake prediction and loss estimation, or flood protection. Guest speakers include science and engineering faculty from SJSU and other Bay Area universities; representatives of government agencies such as US Geological Survey, Environmental Protection Agency, and the California Air Resources Board; researchers from non-profit organizations such as the Monterey Bay Aquarium Research Institute; and industry representative from companies such as Liquid Robotics, Picarro, and Bloom Energy. Students are asked to read additional material related to the speakers and then respond to a prompt. A sample prompt related to a speaker on coral reef destruction follows:

> *Dr. Toa'fa Vaiaga'e, Director of the American Samoa Environmental Protection Agency (AS-EPA), has hired EnvironSJ to help set priorities for developing mitigation programs. His annual budget is $500,000, so he cannot implement every suggestion in the LAS at once. He has hired you to help him determine the top priorities for his limited budget. He has asked you to include:*
>
> - *A summary of the top few contributors to coral reef destruction in American Samoa;*
> - *Identification of the top two goals and projects you would recommend from the LAS;*
> - *Identification of the first steps the AS-EPA should take to get these projects going.*

As a semester culminating project students must write a proposal to address a current environmental issue. Proposals may recommend the implementation of an environmental process for use in production, the purchase of a product for use by a client, the design of a product for future sales, etc. Students are required to identify and research a problem and present a solution that establishes the need for the recommendation and presents clear steps for its implementation. Typical proposals related to the geosciences include solutions to water shortages, storm runoff management, development and delivery of alternative fuels and energy sources, chemical or waste disposal, development of environmental sensors, soil remediation, and sustainable practices.

An important goal of ENGR 100w is to help engineering students understand that solutions to the world's complex problems require an interdisciplinary approach that includes input from many stakeholders. Examples are engineers, scientists, economists, sociologists, lawyers, and policy makers, as well as end-users. This approach of hosting exciting speakers who discuss the latest problems and solutions related to earth and environment issues provides important real-world context to what engineering students are learning in their other technical classes. It also helps engineering students learn how to communicate their important findings to a variety of audiences. Since most engineering and geosciences students are required to take writing and/or oral communications courses as part of their curriculum. An approach like this could be easily implemented at many universities without having to make major curricular changes.

Reference

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Integrating Engineering Concepts to Introductory Geoscience Courses

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My approach in teaching the integration of geosciences and engineering stems from my mineral industry experience. Before I became an educator, I worked in the mining and mineral exploration industry for a decade. I was a part of a team that discovered the $13 billion Sepon Cu-Au mine in Laos and was intimately involved from grassroots exploration to bankable feasibility studies including global road show presentation aimed at raising project financing. As the senior geologist for the bankable feasibility stage, I had the opportunity to transition the project from a geologically-driven status to an engineering stage. This meant interfacing with different engineering aspects –with mining engineers in the design of 3D mining and ore reserve blocks, with metallurgical engineers in the optimization of the process design, with environmental engineers in the EIAs and remediation, with civil/geotechnical engineers in the mine and community infrastructures and with safety engineers as the project is uniquely situated in a high UXO (unexploded ordnance) contaminated area (Ho Chi Minh Trail).

As an economic/resource geologist by training, a good number of my lecture hours and lab activities are focused in the conceptual understanding of the formation of earth's resources (petroleum, mineral and water) and its exploitation and sustainability. I prep up the class by analyzing the components of their cell phones and making them aware of the ultimate source and amount of raw material mined to produce these components. Furthermore, the class is introduced to Nikolai Kardashev's 4 types of advanced civilizations and how each type *exponentially* differs from the source and collective means of harnessing their energy and mineral resources. Prof. Michio Kaku in his book Physics of the Future aptly gave specific examples of these types namely - Type I – planetary scale (ex. Buck Rogers), Type II – stellar scale (Star Trek w/out warp drive), Type III – galactic scale (Empire of Star Wars) and Type IV – extragalactic scale (Q entity of Star Trek). We are now at a critical transitory stage from Type 0 to Type I where our advances and global networking in software engineering, trading, travel and banking are still ironically powered by fossil fuels. Critical in the sense that we need to transition to other energy and mineral resources apart from the current fossil fuels and base metals that propelled us from pre-industrial to industrial and information ages. Critical in the sense that in spite these advances in technology, we are still separated by our political, religious and religious biases that can lead to total annihilation due to our nuclear and other weapons of mass destruction. Engineering solutions, sustainability and compassionate tolerance are the keys to this transition while we technologically prepare ourselves for interplanetary travel and resource exploitation. Otherwise, we, as a species, will suffer the fate of the Easter Island dwellers who suffer the "tragedy of the commons".

This industry experience heavily influences the way I run my introductory geology courses that focuses on exploratory labs first and a follow-up summary lecture later (FLIP classroom). These labs are focused on fundamental physics and chemistry concepts and its real world application in geosciences and engineering integration. 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. It is in the design lab that I introduced the engineering concepts of flowcharts, timelines and cost analysis. Connecting these lessons to real-world experience gives it more meaning and incorporating design labs give the students a sense of ownership.

I have 5 major lab activities that integrate engineering (in particular mining and process engineering) namely – Modeling, Uncertainty Calculations, Drilling Simulations, Mineral Separation with cost analysis and a Fieldtrip to a quarry and an underground mine

There are three main goals that I want to gain from this workshop – share, collaborate and disseminate. First, I would like to share the pedagogical skills that I developed in teaching geoscience/engineering integration with a strong emphasis on real-world applications coming from my years of experience in the mineral/exploration industry and teaching in 9-12 public education. Second, I would like to actively collaborate with and learn from my fellow educators the challenges they faced in teaching this multi-disciplinary integration to non-STEM majors and the teaching methods they employed in overcoming these obstacles. Part of this collaboration is to formulate and developed lesson plans and activities that uses engineering in geological exercises. This is then followed-up by designing an assessment tool to track down the success of such collaboration. Lastly, I would like then to disseminate and publish these newly developed teaching tools to other colleagues and possibly to 9-12 educators as well.

Finding Interdisciplinary Common Ground for Sustainability

Brenda B. Bowen

The grand challenges facing society today-- climate change, depleting natural resources, environmental degradation, global spread of pollutants, and the underlying links between these environmental issues and social, economic, and political complexities, require that we train students who are brave enough to try to tackle these issues in a new interdisciplinary way. However, this is no easy task. Disciplinary paradigms, biases, and perspectives vary greatly, and interdisciplinary instructors must be willing to step far outside of their comfort zones if they might transcend these foundational differences in the classroom.

Before this year, I thought I was an interdisciplinary geoscientists. My research focuses on fluid-sediment interactions and mineralogical and geochemical sedimentary records of environmental change. I work on a range of scales using a variety of high-tech tools and collaborate with diverse geochemists, hydrogeologists, microbiologists, and palynologists-- so I'm interdisciplinary, right? I thought I was bridging disciplines teaching inherently interdisciplinary courses such as Geologic Remote Sensing, CO_2 Sequestration, and Oceanography that integrate Earth processes, human impacts, technology, and engineering (although I admit that I approach the latter as an aficionado rather than an expert). However, the more I learn about the hypercomplex nature of environmental and sustainability challenges, the more I recognize the "Earth science-centric" nature of my perspective and the need to bridge much further outside of my discipline if I am to effectively teach interdisciplinary sustainability themes.

Interdisciplinary research "integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (National Academies, 2004). The National Science Foundation states that they have "long recognized the value of interdisciplinary research in pushing fields forward and accelerating scientific discovery. Important research ideas often transcend the scope of a single discipline or program…the integration of research and education through interdisciplinary training prepares a workforce that undertakes scientific challenges in innovative ways" (National Science Foundation, 2012). But, how do we really "transcend" our disciplines? Conflicting disciplinary norms, differences in methodologies, scope, expectations, traditional institutional academic barriers, mismatches in the problems that are considered important, differing assumptions about the desired results, and the overarching challenge of finding a jargon-free common language inhibit truly interdisciplinary initiatives (Schmidt and Moyer, 2008; Fischer et al., 2012).

The University of Utah's Strategic Vision (June 2012), includes "the pursuit and practice of sustainability" through the promotion and coordination of "interdisciplinary and cross-campus sustainability research, learning, and programs." The Global Change and Sustainability Center at the University of Utah is working to promote interdisciplinary research on the environmental and sustainability issues and to produce leaders who are prepared to find creative solutions to the environmental and sustainability challenges facing our planet. The Center links eight colleges (Science, Engineering, Mines and Earth Science, Architecture and Planning, Social and Behavioral Sciences, Health, and

Humanities) and over 15 departments, and thus I start to realize my previously limited notion of interdisciplinarity. One of my primary duties as Associate Director of this Center is to teach interdisciplinary sustainability-focused courses such as "Global Changes and Society." This is a graduate level project-based course that includes students from many disciplines including geology and geophysics, atmospheric science, mathematics, biology, civil and environmental engineering, mechanical engineering, geography, and city and metropolitan planning. The course aims to help the students learn to speak a common language to practically address sustainability questions, each bringing their own expertise to bear as they explore the connection between Earth systems and human systems and work to find real world solutions to wicked problems.

There is widespread recognition of the importance of interdisciplinary education for sustainability, and sustainability curriculum programs are growing. The Council of Environmental Deans and Directors of the National Council for Science and the Environment found that since 2008 the number of interdisciplinary environmental and sustainability degree programs among four-year colleges and universities in the U.S. increased by 57% -- and the number of schools hosting such programs increased by 29% (Vincent et al. 2012). These trends also reflect the growing job opportunities in sustainability and the "green economy." Bureau of Labor Statistics data indicate that green industries are growing faster than the overall economy and U.S. states that have stronger green economies have fared better during the economic recession (Pollack 2012).

As a geoscientist, I recognize the need for students who will work on complex environmental issues to understand fundamental Earth systems-- the physical, chemical, and biological processes that govern rates of change over magnitudes of scale. Practitioners of sustainability must also understand possibilities for engineered solutions, for creatively applying science and technology. But is that enough? So many scientists and engineers, even those working on critical topics that clearly have implications for resource management and policy, stop shy of stepping out of their seemingly objective world of science and engineering. STEM students are not trained to bridge from the scientific method to value judgments, and thus miss opportunities to communicate the significance of their work to policy makers and the public. I strive to work at this fringe-- pushing Earth scientists into a realm of interdisciplinary awareness and guiding them towards a recognition of the need for creative communication to bridge into the realm of policy, decision making, and public perception to promote sustainability. Rather than simply bringing researchers in different fields together, we need to cultivate a new kind of scientist who will be able to more easily bridge interdisciplinary divides (Schmidt and Moyer, 2008).

A recent discussion on these challenges in Science (Pfirman, 2012) gave the following recommendations for interdisciplinary scholars:

- Prepare yourself for new ways of working, thinking, and interacting.
- Specialize within your interdisciplinary research area. Avoid the tendency to branch out too quickly and in too many directions, which can diffuse your impact.
- Focus on your disciplinary strength and skills. It may sound counterintuitive, but in many situations your value as an interdisciplinary colleague is directly proportional to your skills in your own discipline. Keep up with the latest literature and theoretical developments in your disciplinary field so that you will be prepared to apply new

knowledge and skills in diverse areas.

- Build core competencies that sustain interdisciplinary research by taking courses or learning on your own. For example, you could take courses that use the case study method to enhance interdisciplinary skills or include practice reviewing interdisciplinary papers and proposals.
- Attend seminars and workshops in other disciplines. Participating in research seminars outside your own department is a great way to expand your thinking, add a new batch of colleagues to your network, and develop expertise in new research areas.
- Seek new mentorship. The old model of one scholar, one mentor is fast becoming a distant memory. Find a mentor or two from beyond your field to help broaden your mindset and approaches.

Techniques to Teach Sustainability in Multi-Disciplinary Classrooms Comprised of Engineers, Geoscientists, and other Disciplines

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I believe teaching sustainability to engineering and geoscience students in integrated courses requires new approaches to course planning, lesson development, pedagogy, student expectations, and assessment. I have had experience teaching to multiple disciplines in integrated classrooms in three different sustainability-focused courses offered multiple times. One challenge I have noted is the need to reconcile differences among students from engineering versus geoscience versus other disciplines. I have learned that differential teaching and learning (DTL) must be factored into the course plan and delivery. The purpose of this essay is to describe DTL and to present a few of my experiences with techniques appropriate when significant background differences exist among students in the course.

DTL is a common circumstance in multi-disciplinary classrooms at the upper division and graduate levels where students from different majors enter a course with different levels of knowledge, skills, expectations, capabilities, and pre-conceptions. In my first efforts, I found teaching to this diverse set of students with approaches I have used in my previous engineering-student only courses were not as successful because the assignments and activities were being designed with a single discipline focus or being pulled from my past single-discipline teaching experience. I had to adjust my teaching and learning techniques. Teaching techniques that have been successful for me to teach to diverse student cohorts include: (1) providing clear learning objectives, (2) co-teaching (from course planning to course delivery), (3) using project-based learning, (4) facilitating communication, and (5) incorporating linked learning activities.

Having clear course and lesson learning objectives is a critical first step for aligning the expectations and foci of students in multi-disciplinary classrooms. It is important for the lesson learning objectives to be provided to the students before class activities for that lesson are assigned or occur (i.e., before reading, homework is assigned and of course before the class session). It is also important to present the collection of lesson learning objectives in a hierarchical manner so students from the different disciplines can see how the content in a class and from several class sessions in a module is linked together. Engineering students at the University of Utah are moderately familiar with learning objectives, but students from most other majors have not been widely introduced to lesson learning objectives. The use of them helped all students in the class come adequately prepared and focused to conduct the lesson.

I believe DTL challenges associated with teaching broad sustainability topics to a multi-discipline classroom may be mitigated if the course is co-taught by instructors from different disciplines. I have co-taught three courses multiple times and in each case the interaction with my co-instructors was essential in creating a course plan that could appeal to engineers, geoscientists, and other majors, accounted for our teaching styles, and provided a coherent sequence of topics and lesson activities for the students. In all courses classroom activity has included discussion time and this is where the co-teaching is essential to a set of students from different disciplines – to provide them role models of disciplinary interaction appreciating the perspective of other disciplines. This is especially essential if the disciplines of the students are disparate (engineering, science, humanities, and social sciences) where pre-conceived notions of the other majors inhibits respect/value of opinions initially.

Another DTL technique I have had success with is project-based learning (PBL). My experiences with interdisciplinary teaching have included both PBL experiences and traditional classroom activities. But, I have found PBL to be the most effective. Using projects enables the instructor (or instructor team) to set the scope of the projects to require a range of disciplines to participate. This helps to illustrate not only real-world projects where multiple disciplines typically must interact, but also the value of other disciplines to successfully complete projects. This is even more essential for sustainability topics and projects that are inherently multi-disciplinary. I have found students in integrated sustainability courses will learn from each other (even from disparate disciplines) if there is a clear project that requires them to integrate their efforts. Sustainability projects come in many shapes and sizes but the need for a range of disciplines can nearly always be found. Finding ways to integrate engineers with geoscientists with other majors is a challenge, but accomplishing it with a project-based experience has worked well for me.

Communication is a critical tool to teach sustainability topics to integrated classrooms. First, as mentioned previously it helps for the instructor (or instructors) to have the broad knowledge across disciplines to lead discussions and lecture effectively. As a civil engineer I have had to learn a great deal about geosciences and other disciplines to improve my teaching effectiveness in multi-discipline classrooms. I have students from different disciplines and from different backgrounds enter a course and have different thoughts on what is the expected workload, what is the expected quality of work, and how they communicate their thoughts. It is important to bring the entire class to a common ground. In the case of course mechanics, instructors must role model working with multiple disciplines. The instructors must clearly state the expectations and continuously reinforce them. And the instructors must work with students to prepare homework and project submittals to match a common structure that meshes the different disciplines and forces students to incorporate approaches and ideas from different disciplines. Second, students need to be engaged in activities with other students that require extensive communication. I have used think-pair-share and small group discussions and made sure the pairs and groups have multiple disciplines. This helps to build collegiately among the different disciplines and helps to develop a common language while accomplishing lesson learning objectives.

Lastly, a very effective technique to integrate engineers, geoscientists, and other majors is to use linked-learning activities. Linked-learning activities typically involve independent courses joining in learning activities that require skills from multiple disciplines to achieve the total problem solution. I have accomplished this with homework assignments, projects, and online discussions that engage students from multiple courses taught by different instructors. This is a logistical challenge and most importantly requires having excellent working relationships with the partner instructors and also a solid working knowledge of the other disciplines and course topics involved.

In sum, in addition to the five specific techniques described above a critical element of effective teaching of sustainability to engineers, geoscientists, and other disciplines in an integrated classroom is to adapt and adjust course content, teaching techniques, learning activities, and expectations as the course progresses. I rarely have to do this for a Civil Engineering course, even when offered for the first time. But I have had to do it for my interdisciplinary sustainability courses, even those that I have taught multiple times.

A few thoughts on the integration of engineering and geoscience

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I am a geologist rather than an engineer, so my comments should be read with this perspective in mind. The first place to look for opportunities to integrate engineering and geoscience at the undergraduate level to "[prepare] students for the workforce" is in engineering geology or "geology for engineers" courses. It seems that a declining number of geoscience departments offer these courses, or require students to take courses in applied geology. As a consequence, relatively few geoscience departments produce graduates who are ready to provide relevant geological input to the engineering design process. Geology students who are not specifically trained as engineering geologists typically lack knowledge that is of practical utility to an engineer. (Geologists also tend to lack knowledge of engineering mathematics, statics, dynamics, or mechanics of materials.) Other opportunities for integration might exist between engineers and structural geologists and geophysicists, all of whom work with continuum mechanics. If geoscience departments do not produce students who can work effectively with engineers, there is little reason to expect engineers to include geoscience input as part of their design process.

The problem of the inadequate preparation of geologists to work with engineers has been recognized and discussed for decades. Geology departments in research universities currently tend to hire and grant tenure to faculty members who will attract external support from NSF (with attendant overhead funding to the university), produce high-impact papers in top-tier publications, and produce a steady stream of doctoral students. Faculty members with expertise in engineering geology are more likely to attract contract funding without overhead, produce MS students and publish in relevant applied-geology journals, and so they are not viewed as assets helping the university or department improve their Carnegie ranking.

The effective integration of geoscience and engineering beyond the college campus requires people who are [1] proficient in their respective field (geoscience or engineering), [2] humble in the face of challenges posed by natural hazards, [3] willing to recognize the limits of their own expertise, [4] understand and respect the expertise of others, and [5] able to work collegially with people whose expertise is different yet complimentary toward the successful mitigation of a problem. In short, geoscientists should understand the role of engineers and be able to provide them with a useful understanding of relevant geological processes and reliable geologic data. Engineers should set aside their seemingly innate superiority complex, accept the complexity of the geological environment, solicit and use geoscience expertise relevant to a project, and design engineered works that must exist within a geological environment with the active collaboration of geoscientists.

Several decades ago, I worked on a case in which all of the children in a family were killed by a debris flow that destroyed the bedroom in which they were sleeping. The house had been built at the base of a hillslope swale that had filled with loose colluvium. During a strong rainfall event after a preceding period of wet weather, the colluvium was mobilized and moved rapidly downslope, destroying the home and some of its occupants. Pre-development site investigation had not included a geologist, and the project engineers did not consider any condition beyond the property lines that extended along the base of the slope. The disaster could have been averted easily if a driveway or side yard had been located below the swale instead of putting the house in harm's way. Many such stories exist in which engineers assume that they do not need geoscience input, but are proven wrong when their design fails to protect the public from recognizable geologic hazards that could have been mitigated.

My general approach in an engineering geology (or geology for engineers) course has been to begin each new topic by creating an empathetic bond between students and someone who has been harmed by a geological event that might have been mitigated or avoided by the proper use of engineering design. I tell the story of a disaster, which might be large or small in scope. If done effectively, this generates a response in students that results in their desire to understand more about the hazard, how to assess the risks posed by this hazard, and how to protect people from the negative effects of this hazard in the future.

I like to use physical models to help students understand the physical basis of geological hazards and their mitigation. Many geological problems associated with engineered works are well illustrated through appropriate physical modeling. I might start with a simple experiment in which students pack tubes with well-sorted sand or gravel, measure the porosity, and transmit water through the tube at a constant and uniform pressure. How easily does water flow through sediment of different grain size? What if we use poorly sorted sediment instead of well-sorted sediment? What are the relevant physical parameters (*e.g.,* porosity, permeability, hydraulic conductivity), how are they defined and how are they measured? What are the relevant analytical expressions that relate to the system we are modeling? What would change if the minerals interacted with the water and became softer or increased in volume or...?

Given the results of a collection of hands-on experiences, we can then begin to understand how sand filters or French drains or earth-fill dams work, using different grain sizes to accelerate or decelerate subsurface water in a controlled manner. And once students think they understand how these engineered structures might work, it is time for more physical experimentation: having students make a sand filter, a model French drain or build an earth-fill dam in an aquarium. Did it work? What were the unexpected results? What were the actual results? How should we change the model? I might follow by having students learn about ASCE standards for sand filters or French drains, or by examining the design of an actual earth-fill dam.

I use simple models of buildings to illustrate building failure during earthquakes. These models are used in the laboratories for our introductory physical geology courses, in association with lectures related to earthquakes. Models of "houses" whose walls are made of compacted flour or dry plaster, and whose roof is made of heavier materials, are put on a shake table to illustrate how adobe homes with heavy vega-beam-and-soil roofs fail during seismic loading. Other models show the importance of shear walls and diagonal bracing. Photographs of buildings destroyed during deadly earthquakes are shared during lab, confirming the importance of proper building practices (mandated by well-administered building codes) in areas affected by earthquakes.

Engineers and their intellectual ancestors have learned from the failure of engineered works throughout history. Long before beam theory or continuum mechanics, the success or failure of a cathedral ceiling or buttressed wall set effective limits to the design of subsequent structures. Geoscientists who seek to work with engineers also need to understand how geological conditions have led to the failure of engineered works. What geological features or parameters must be recognized and quantified in order for engineers to develop safe designs?

To the extent that there is a lack of integration of engineering and geoscience in undergraduate studies at many universities, the best solution seems elementary and time-tested. Hire faculty members with the specific responsibility to work collaboratively across this organizational boundary, and tangibly value the work of applied geoscientists in hiring, tenure, promotion, salary, access to laboratory resources, and access to graduate students at the MS level. Incorporate hands-on experimentation in geoscience courses that relate to engineering. Geoscience faculty members who teach engineering geology should form cooperative relationships with local civil engineering and engineering/environmental geology firms, giving our students opportunities to benefit from their experience. When it is not possible to hire an engineering geoscientist, brief modules related to important engineering-geology topics should be developed that can be used in other geosciences courses. Examples would involve projects about hazards such as landslides and debris flows, coastal erosion/deposition, fluvial erosion/deposition, flooding, liquifaction, building damage due to earthquake vibrations, and expansive soils.

STEM education for the 21st Century

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As an educator I am very passionate about student learning and how well they grasp complex technical concepts. This passion is reflected in all courses, projects and workshops; that I teach, supervise or design. I am also aware that individuals have different learning styles, and I try to design my lectures and presentations to reach the widest possible audience. The overall objective for my classes is that everyone is given a opportunity to do well, irrespective of their learning style.
To achieve this, lectures are planned to follow a logical sequence; with a smooth 'hand-shake' from one lecture to the other. This ensures continuity throughout the class. When it is necessary to move to a completely new subject matter it is conducted as smoothly as possible in an attempt to ensure that the students can follow the transition.

Student evaluations are also given as much consideration as when dealing with students learning styles. For the classes I have lectured, traditional exams are coupled with student research projects. These projects are designed from the course materials, and the students must defend their work orally. Projects provide a means by which students can get their hands 'dirty'. It gives them to opportunity to 'see, feel and experience' the Physics, Mathematics and Engineering involved. Students must be trained to properly understand the Physics associated with a principle, make the appropriate Mathematical deductions, and develop Computational Engineering models to support and represent their findings. In my opinion that this approach is necessary as more complex and interdisciplinary computational models are required to address today's global issues.

Another policy I strictly enforce in my classes is that I meet with my students individually once a month. This works well with small classes. Students are required to have short scheduled monthly meetings with me. I believe that it is important to have sufficient 'face time' with my students, so that potential learning issues are identified early in the duration of the course and steps are taken to amend these issues. I have found that implementing the above model has worked well both for myself and my students.

The Challenge and Reward of Teaching Geological Engineering on the Border

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Teaching geology to engineers is one of the most challenging and rewarding things I do each year. Each year a new class of undergraduate civil engineers often begrudgingly starts the semester in their "required" engineering geology course and by the end of the semester present posters on projects where they proudly display their new-found geologic knowledge and skills. In my class I strive to prepare the students with knowledge to: be able to converse with geoscientists and read geological/geophysical reports, know the basic rock and soil types they will find in the El Paso area and the properties of these materials that an engineer should be concerned with, understand surface and internal geologic processes and how they affect engineering projects and how geophysics is an important tool in the field and the laboratory. In their laboratory they learn to read maps, construct cross sections, predict rock and soil properties by how these materials appear in hand samples, conduct simple geophysical surveys and learn to communicate geology to their colleagues and the general public. The course is capped by a group project where they apply what they have learned to read life situations such as building a light rail system, a new pipeline to bring water to El Paso once our nearby groundwater supplies are depleted, a new housing development – something that they could work on in their lifetimes. Several former students have even called later to tell me that they are actually working on a project similar to what we covered in class! Not only do I find the course challenging, engaging, and often fun), but my graduate teaching assistants (commonly studying geophysics or structural geology) also benefit from learning to communicate science in a different way. I have worked closely with the civil engineering faculty to insure what I teach continues to be relevant to their program and produces students with a clear grasp of why geoscientists and engineers need to communicate and work together.

The Built Environment: A Common Ground for Geoscience and Engineering

John Duggan, Civil Engineering and Technology, Wentworth Institute of Technology

Most of us don't put a lot of thought into the origin of the materials in a paved road, a concrete sidewalk or a brick wall, but we should. We take for granted that the structure is there and serves some necessary purpose. In the context of geoscience and engineering, the composition of a man-made structure, how it was designed, and how it was built are central to evaluating its sustainability. By taking a closer look, the landscape of the built environment can be viewed as a work in progress, a dynamic system at the intersection of engineering, geoscience and sustainability.

Our built environment, that includes our living and working spaces and the networks that link them, is constructed with raw materials extracted from the earth. Design is based on, amongst other things, an understanding of the physical and chemical properties of these raw materials. Efficient design, use and maintenance of these spaces are the essence of sustainability. Teaching and learning opportunities focused on our built environment include field and laboratory research, historical and contemporary case-studies and the study of regulatory and economic factors that drive decision making. In all cases, the concepts of sustainability, such as life-cycle assessment, carbon footprint, protection of natural resources and environmental justice, should be taught with the integrated use of geoscience and engineering principles.

Practicing professionals, whether scientist, engineer, planner or policy maker, have an ethical obligation to consider the effects of their actions on the environment, public health and safety. Teaching that exposes students to the life cycle of natural resources, such as stone, sand, limestone and clay, in the production of building materials (asphalt, brick and concrete, etc.) will prepare them to consider and address the availability of these resources both in their lifetimes and for future generations. Sustainability issues facing the built environment require solutions to challenges of finite natural resources, preservation of open space, energy conservation, etc. These solutions require an interdisciplinary approach by engineers and geoscientists (and others).

This workshop provides an opportunity to identify and develop teaching modules to address sustainability issues with the built environment that bridge the gap between geoscience and engineering. Modules would include: alternative building materials; alternative design and increasing design life; improved recycling and reuse of building materials; and the assessment of technological and regulatory impediments to more sustainable design. Such modules can be developed to enhance an existing course within a discipline or stand alone as a separate hybrid course. Through collaboration at this workshop, there is the opportunity to develop interdisciplinary modules, both relevant to the times and effective in educating and inspiring students.

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Tej Gautam, Department of Petroleum Engineering and Geology, Marietta College

INTEGRATING ENGINEERING AND GEOSCIENCE IN A CLASSROOM

An approach to integrate engineering and geoscience in a classroom is engaging students in active learning and providing them with a hands-on activity that requires understanding of the basic geoscience concepts and solving them with engineering applications. The application of this approach may involve:

1. Analyzing the problem with a multidisciplinary approach
2. Providing a project that incorporates topics/issues from engineering and geoscience and encouraging students to identify problems and to figure out the best solution
3. Simplifying the complex problems into small components and understanding each component separately; some components may need engineering and some may need geoscience concepts to understand

Many problems around us are multidisciplinary in nature. A multidisciplinary teaching approach broadens the thinking of a student with a wide realm of knowledge. A project based study would strengthen the idea of a multidisciplinary approach when a specific class project involves the understanding of geosciences, engineering, and environmental issues. Environmental consideration is also very important to achieve a sustainable solution of a real world problem.

In general, geoscience refers to all sciences dealing with the study of earth, concepts and processes of earth's systems, and understanding the natural environment and resources. There are various engineering problems related to hill slope processes, exploration and utilization of earth resources, construction of infrastructures such as roads, dams, and foundations. Without the sound knowledge of geological processes and earth materials, it would be difficult to plan the effective mitigation methods for these problems . Simplifying complex problems by presenting models and comparing them with daily life examples from real world situations would help students to understand the scientific concepts.

Working in a group or peer setting can also be effective to understand complex problems. As it is important for an engineer to understand geoscience concepts to address those problems and provide them with sustainable solution, a geoscientist need to know the options and availability of engineering technologies to understand and to provide the appropriate recommendations or suggest proper models. A soil slope stabilization project can be an example where the multidisciplinary approach can be applied. It involves understanding the soil type and its behavior, determining mechanics of the slope movement, analyzing driving and resisting forces, determining possible pore pressure condition, protecting environmental sustainability, and finally providing an appropriate method of stabilization and design criteria. The concepts of both engineering and geoscience are necessary for the successful completion of such projects.

Reinventing the Introductory Geology Course for Engineering and Other Quantitatively-able Students

Laurel Goodell
Dept of Geosciences, Princeton University
February 2013

Our fairly traditional GEO203: Physical Geology had for years served as entry into the department. However, enrollment in the course had been steadily declining; we found that many of our majors were entering the department via topical "Freshman Seminars" and that upper level students in other departments, including engineering, were taking upper level courses and opting out of taking GEO203 altogether.

We also noted that the introductory geoscience courses are typically taught at a lower and less-quantitative level than introductory courses in the other sciences or engineering. While these courses can be valuable, engaging and indeed do attract students to the geosciences (as happened to me), we wanted to re-invent the introductory course in order to specifically target and attract two particular types of students: civil and environmental engineering majors and also students who have quantitative skills and science backgrounds typical of someone considering a major in, say, math or chemistry or physics. These students are not particularly attracted to the standard Physical Geology course.

Thus, we (Professors Jeroen Tromp and John Higgins, graduate student Jonathan Husson and myself) have undertaken a major revision of GEO203, renaming it "Fundamentals of Solid Earth Science." It was offered for the first time in the fall of 2012, with the following course description: "*a quantitative introduction to Solid Earth System Science, focusing on the underlying physical processes and their geological and geophysical expression. Topics include basic physical conservation laws, examples of constitutive relationships, waves, transport phenomena, geopotential fields, geologic time, basic thermodynamics and mineralogy. Single variable calculus is a prerequisite.*"

Our goal is to present and teach the geosciences as an interdisciplinary field that is as modern, quantitative and rigorous as any other science or engineering course of study. We hope to blur boundaries by engaging engineering students in geoscience problems and applications, and exposing non-engineers to engineering approaches and perspectives. The course fulfills a requirement for Engineering students as well as for Geoscience majors.

The course has weekly precepts and extensive problem sets instead of weekly laboratory sessions, although we also take the students on two field trips and use some lab-like activities and in the problem sets. In additional to calculus, we also include basic linear algebra and introduce students to MatLab.

The Fall 2012 version was moderately successfully, with mixed student reviews. One problem is that there is no appropriate textbook so we have used a combination of faculty-generated class notes (perhaps a textbook in the future?) as well as suggesting portions of existing texts; these reading assignments need to be made more explicit. We also need to do a better job of integrating geology topics with the quantitative material, and of integrating lecture with precept/problem set material.

But with about a 50:50 mix of engineering students to non-engineering, about 1/3 of the class are taking upper level geoscience courses for the spring. Several students have started working in Geoscience research labs and are planning geoscience topics for their junior and senior independent work. We're currently reassessing and revising in anticipation of the second running of the course in the Fall of 2013.

Teaching at the Intersection of Geoscience and Engineering

Mary Beth Gray, Geology, Bucknell University

I have the pleasure of teaching geology to first year civil and environmental engineering students through an introductory course entitled "Geology for Engineers". I view my main teaching challenge to be helping new engineering students understand the relevance of geology to engineering. If they can develop an appreciation for why they need to know basic geology, they will be more likely to: (a) be eager learners in this required course outside their discipline; (b) be alert to geologic considerations as a practicing engineer; (c) know how to access, understand and integrate geologic data; (d) know when to consult a professional geologist and how to effectively communicate with a professional geologist on their team; and (e) be more likely to continue learning more about earth processes either formally or informally in the future. It's a shame that about 80% of these students have no prior exposure to geology. For this reason, they tend not to understand why geology is being forced upon them while they take concurrent courses in other topics that they view to be much more obviously related to their chosen profession such as calculus, mechanics, and computer-aided drafting. I embrace this teaching challenge through a variety of approaches, each of which requires the students to articulate for themselves how geoscience relates to engineering.

On the first day of class, I ask them why they think this course is required for their major and we start to build connections immediately. We talk about the topics we will cover over the course of the semester and students begin to see how geoscience informs and relates to engineering decisions. On that same first day, I urge them to interrupt any activity at any time in the course when they cannot see a direct connection between the topic being addressed (whether its silicate minerals, fracture patterns in rocks, or bedrock mapping) and their goal of becoming an engineer. On occasion, I have had students do just this. These have been some of my favorite teaching moments. I put aside the lesson plan for the moment and we step back and look at the big picture. I redirect the questions to the class group: why is this topic important, what does it have to do with engineering and how does it relate to potential hazards, engineering materials, or natural resources managed by engineers, for example? In other words, "Who cares?" The students often help each other find the answers to these questions and it usually involves a lively discussion that inevitably results in numerous newfound connections between the geology du jour and their engineering pursuits.

I have developed a library research project that invites students to explore a specific topic of interest to them and present their findings to the class in the form of a poster presentation. The students are required to select a topic that lies at the intersection of geology and civil engineering. Geosciences and civil engineering are equally broad and the crossover area between them permits a seemingly endless range of choices for a research project. I offer the students a list of forty or so topics (e.g., hydrofracking) or case studies (e.g., the Vajont Reservoir disaster) they could research, but students are also encouraged to come up with their own ideas. Most of the poster consists of two separate panels, one for geology considerations and another for engineering considerations. The abstract, context/background information and summary sections are areas where students elucidate the connections between the two components.

Extra credit is a remarkably effective motivational tool for encouraging and recognizing the effort involved in going to co-curricular events that in some way link geology to engineering. Throughout the semester I announce 15 or so extra credit opportunities from a diverse menu of guest speakers, field trips, and workshops that regularly occur on campus. Students are permitted to get credit for participating in up to three of these events (amounting to a maximum 3% increase in the their test average at the end of the semester). To earn credit, students are required to submit a one page write up within one week of the event, half of which is a summary of the content and the other half is their response to the event. I really enjoy reading these responses because the students often report making discoveries about their own interests and misconceptions, and further develop points of view on complex societal questions that both geologists and engineers must tackle.

Given the degree to which geologists and engineers work together in the field and the degree to which these two disciplines overlap, it is critical to increase understanding and traffic between them. Sustainability is one of several key issues of this generation that straddle the boundary between the geoscicences and engineering. There is no better time to work hard in the classroom to make the relationship between the two disciplines transparent.

Academic and Industry Collaborative Approach to Integration of Engineering with Geoscience

Don Hellstern, Geotechnology Institute, Brookhaven College

As a teaching administrator at the Brookhaven College Geotechnology Institute (BCGI), I not only maintain associations with numerous geoscience professionals and organizations but also teach geoscience courses. The mission of the BCGI is threefold, promoting Earth Systems Science Education:

- for professional geoscientists through seminars and industry events;
- for teachers at all grade levels by providing instruction and classroom-ready tools; and
- for children of every age by personal interaction with geoscientists and exposure to career opportunities.

Additionally, the BCGI houses the Geographic Information Systems department. Brookhaven college is one of seven sister colleges that form the Dallas County Community College District (DCCCD), which serves a large metroplex area. Over a year's time, our small geology department typically offers courses in Earth Science I and II, Physical and Historical Geology, Environmental Geology, Oceanography, and Meteorology. The great majority of students taking these classes are non-majors enrolled in Earth Science I. Successfully engaging students to enroll in an additional geoscience course beyond our introductory Earth Science is challenging. The task becomes what sometimes seems like a competitive sport when posed against the attraction from other disciplines. The underlying reason is that, unfortunately, many students' academic interest in our discipline is simply to satisfy core science requirements.

Several universities within our region, where many of our students ultimately transfer, maintain thriving engineering programs. However, engineering courses are currently taught at only one campus within the DCCCD. Following a national trend to conscientiously address Science, Technology, Engineering, and Mathematics (STEM) education, our college has concentrated on developing vibrant programs for science, technology, and mathematics – while momentarily lacking engineering. However, an interest in engineering professions persists among our student body and I believe this gap in programming offerings can be partially filled by rigorous geoscience courses that embed introductory engineering foundations. With the collaboration of industry professionals linked through the BCGI, these courses would introduce students to laboratory and field experiences that are currently unavailable. This type of early, pertinent exposure to engineering practices could harvest additional students into a field they had not previously considered. For students with their sights already set on engineering, these experiences would help maintain their interest to pursue further studies at the university level. Potential for building a relationship that may provide internship opportunities and future full-time employment also exists with such collaboration.

Integrating Geoscience into Water Resources Engineering

Manoj K Jha, Assistant Professor, North Carolina A&T State University

Since fall of 2010, I have been teaching few undergraduate courses in water resources areas including "hydrology" and "water resources engineering design". My research interests are in the broad area of surface and subsurface hydrology, watershed modeling, modeling evaluation of best management practices for non-point source pollution reduction, and impact assessment of climate variability and change and land use changes.

I think that my teaching and research interest connections with geosciences are followings:

a) Role of climate variability (mainly precipitation) in determining design discharge for designing water resources infrastructures including reservoirs and storm water sewer systems; Concepts of ENSO and non-stationarity
b) Sustainable water resources management for limited fresh water resources and under current variable climate and predicted changing climate
c) Effect of land use, topography and soil characteristics in runoff generation processes (Curve number approach, hydrograph approach, others)
d) Effect of watershed characteristics in streamflow routing in connection with flood frequency analysis for hydraulic structures
e) Origination, movement and discharge of groundwater for baseflow contribution as well as for pumping fresh water resources; role of geology such as karst area, sink holes, etc.

I incorporate above topics into my teaching through example problems and/or just plain discussions. But I plan to add/refine more as it relates to my interests, and I think it is important for future water engineers to have some basic knowledge on these topics.

Aside from the topics listed above, I am sure there are more which could potentially be integrated into my teaching. But this is where I need learning and expanding my horizon on what could be included and more importantly how (which methods) could be best implemented for better explanation and retention of the subject material. I hope this workshop will help me find connections in learning and expanding my thoughts on integrating geosciences into water resources engineering.

I would like to expand on erosion and sedimentation and its impact on water resources structures; for example, how design methods could be extended to include impact of sedimentation in irrigation canals, reservoirs, detention ponds, etc.

I would like to see and learn from others' experiences on integrating geoscience into engineering. I may not find exact links to water resources related topics in this workshop, but I hope to find some clues through case studies and on implementation methods. I am looking forward to gain some experience and ideas that I could use in my undergraduate teaching. Finally I would like to thank the workshop organizers for providing us with this opportunity to learn which will eventually help future professionals and workforce equipped with a better knowledge.

<u>Active learning strategies for enhancing the integration of geoscience and engineering</u>

Francis Jones, Earth Ocean and Atmospheric Sciences, UBC.

My current position in the Earth, Ocean and Atmospheric Sciences Department (EOAS) at UBC involves course, curriculum and instructor development for geoscience as well as engineering courses, and I also teach applied geophysics. EOAS administers both science and engineering degrees, and students in each program take many of our core courses together, including the senior three week field school. Therefore I am fortunate to work in a department in which engineering and geoscience are naturally integrated.

To my mind, integrating engineering and geoscience is basically all about “increasing complexity” and “adding context”. This is a shift from teaching routine problem solving or facts-based skills towards helping novices think and act more like experts. My approach to facilitating this shift involves reducing content delivery (lecturing or generating “material”) in favor of constructing activities that use real settings and professional information as well as basic knowledge about math, physics, etc. Ideally, activities should make thinking visible so that both students and instructors can react to it productively. Here are two specific examples of strategies to support this approach.

A few years ago, I completed a collection of online resources about applied geophysics. One objective was to develop self-contained activities that emulate professional decision making. In one example, the student determines whether seismic surveys are suitable for a given site characterization task. At each stage of this somewhat game-like exercise, information is read, corresponding activities completed, then decisions are made using branch point buttons. Feedback is provided for every possible choice so that students learn directly from mistakes just like in the real world, but in the safety of a simulated setting. Six experimental interactive case studies or “action mazes” can be found in the Applied Geophysics Learning Objects repository ([i]). The scenarios were built using a free tool called “Quandary” ([ii]).

As another example, we incorporated real but redacted consultant’s reports into two lab exercises in a hydrogeology course for third year geoscience and engineering students. It took several iterations to discover which aspects of these types of writings beginners could use and which contained too many hidden assumptions that were familiar to experts but obscure for novices. To help students find and use the information, an online quiz was developed to guide student reading rather than to test specific knowledge. The types of questions used for this task can be seen in reference ([iii]).

Why these approaches are valuable in preparing students for the workforce

Enhancing active learning supports the integration engineering and geoscience by helping instructors to shift from the old “topics list” perspective, towards learning goals that reflect what students will be able to DO as they grow in expertise. Developing activities involves careful task analysis to articulate exactly what is involved when designing or making decisions. This helps to (a) identify “expert blind spots” (aspects that are implied or assumed by experts) and (b) define frameworks that students can use as learning guides and when applying knowledge in new settings.

Mixing practical, fundamental, and scientific aspects is also positive motivationally and enables opportunities for students to carry out “preparation for learning” or “discovery” exercises. These involve first encountering the problem without sufficient knowledge to solve it so that the challenges and priorities can be recognized. Subsequent learning then becomes more efficient and more permanent.

These kinds of more "mature" thinking skills are desired by employers, as was shown by a hiring practices study (reference [iv]) we carried out in 2010 at a large mining and exploration trade show.

Ideas for building upon this base to strengthen integration of geoscience and engineering

Integrating engineering and geoscience is easier when there is both discipline specific expertise and knowledge about how learning happens within the particular discipline. This so-called "pedagogic content knowledge" can be improved either with a little focused support from geoscientists or engineers who also have expertise in post-secondary science education, or by encouraging faculty members in a department to participate in mentoring and collaboration programs. Personally, my earlier experiences as an electrical engineer, oil, gas and minerals exploration geophysicist, and in academe, combined with recent expertise gained in science education, have all helped improve my ability to integrate engineering and geoscience in my teaching, and to help others do the same.

Integration efforts would also benefit from more reliable measurements of the effectiveness of specific teaching and assessment strategies, including impacts on various demographics. Pedagogic research can be time consuming, but small scale strategies are possible. For example, we routinely use surveys with short, focused questions to rapidly improve strategies such as the use of permanent learning teams. We also incorporate pre-post testing into normal assessments in order to compare conceptual understanding before and after a course, module or activity. Results can be used to demonstrate or improve efficacy of teaching strategies.

Scaling up the integration of geoscience and engineering for larger numbers of students is another challenge. The action mazes, and quizzes used for guiding first encounters with professional readings mentioned above were both built partly to address this challenge. More research is needed however to determine whether such innovations do in fact improve the reliability and efficacy of self-assessment, evaluation, and delivery of feedback.

After six years of working as part of the EOAS science education initiative, I have seen faculty shift from a content delivery focus towards a student-centric, active learning perspective. Students now spend more time wrestling with higher level concepts, they benefit more from rapid, useful feedback from themselves, their peers, and the instructing team, and they graduate having learned to incorporate the practical and theoretical perspectives of both engineering and geoscience. As an added bonus, faculty have also found that their time in class, and their relationships with students, is more enjoyable, more professional, and more productive.

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[i] Action maze activities are items 20, 21, 22, 26, 27 and 28 at http://urls.bccampus.ca/h6
[ii] http://www.halfbakedsoftware.com/quandary.php
[iii] http://eos.ubc.ca/research/cwsei/resources/Piteau-questions-only.pdf
[iv] https://circle.ubc.ca/handle/2429/37246

I must confess at the outset that these are not the words of an experienced and wizened professor of engineering and the geosciences, but rather the observations of an aspiring educator who has just finished teaching their first full class. While I have taught lab sections of various engineering classes, and had some opportunity to study learning theory, I will keep my remarks accordingly brief.

Engineering students, generally speaking, are motivated to learn any topic or subject they believe will be useful to their career goals. As a life-long student myself, this seems to be more true in engineering than in some other disciplines with which I am acquainted. We as instructors within the engineering sciences, however, often come to class with somewhat more formidable learning objectives than in other departments, particularly at the undergraduate level. I use an initial assessment of the students to give a gauge of both motivation and prior knowledge, and to give them an idea of the direction and breadth of the material to be covered. Because people tend to learn most effectively through a variety of routes, and because issues related to the acquisition and retention of complex engineering concepts are crucial to society and to the students, it seems advantageous to use any tools that foster and maintain interest. (To be honest, I also find it irritating on a personal level to look out over a bored or sleepy class, but it's easy to remind myself that this is a clear indication of failure on the instructor's part.)

To that end, I try to incorporate within lecture material: visual, auditory, and when possible, tactile elements. My experience is that this is fairly standard within engineering and the geosciences. Individual and small group projects often provide a mechanism for assimilating conceptual material into solid hands-on investigations. I include several such efforts within a course, starting with somewhat straightforward projects, usually on an individual basis, and progressing to team projects that involve more in-depth research, the synthesis of integrated or related concepts, and if at all possible, elements of design or decision making for specifications based on the best available real-world data.

In so far as the integration of geosciences and engineering, the relevant subject I am teaching, "Materials and the Environment," necessitates examining the relationships between hydrology, mining, energy, atmospheric science, materials science and economics. The Industrial Revolution has shifted the use of materials from almost entirely renewable resources to nearly complete reliance on nonrenewable resources, both in terms of energy and raw materials. Most of these feedstocks are derived from ore bodies, with reserve and resource bases playing critical roles in mankind's future, as well as implications of resource extraction affecting water and air quality. Although the integration of these related subjects is implicit, I am hoping to gain insights during the workshop on innovative mechanisms for presenting and teaching this topic.

Uncertainty and Risk: Bringing the Geosciences into the Civil Engineering Classroom
Gretchen Miller, Zachry Department of Civil Engineering, Texas A&M University

I suspect that certain concepts in my groundwater course irritate my students. That a rock labeled "sandstone" could have a hydraulic conductivity anywhere from 10^{-10} to 10^{-6} m/s, an outrageous range of five orders of magnitude. That that rock is definitely sedimentary, unless of course it is slightly metamorphosed. That a wide array of possible subsurface conditions could all produce the same map of the water table. They want to know what the answer *is*, not what it could *possibly be*. And therein is the teaching opportunity.

Engineering firms increasingly require adroit workers, who are flexible in their approach to problems and who can quickly learn new skills. However, engineering students can become rigid in their thinking; after all, we drill them with years of practice problems that have one right solution. However, learning about the geosciences, with their relatively imprecise earth materials and random hydrologic processes, can help students overcome their reliance on formulaic ways of viewing the world. In my courses, I try to foster alternate modes of thinking through the inclusion of an emphasis on several important geoscience concepts.

Specifically, I think three principles from the geosciences can help all engineers to become better problem solvers and ultimately produce better designs:

- Embracing ambiguity, uncertainty, and risk
- Analyzing a system holistically and recognizing scale-emergent behaviors
- Understanding non-experimental, observational based modes of scientific discovery

Although these principles can be taught in many different contexts, ones that are more familiar to students seem to ease the transition into more sophisticated modes of thinking. For example, in my introductory water resources engineering classes, I reintroduce students to concepts from statistics, now applied to extreme events, like floods and droughts, and even more mundane ones, like the weather for over the past week. We analyze precipitation and streamflow data from our watershed monitoring site on campus (the more recent, the better), and discuss how campus infrastructure has to be designed to accommodate both low flow and high flow events (e.g., sprinkler runoff vs. busted fire hydrants). This course is often the first time that students are exposed to the ideas of probabilistic design; that there is no "factor of safety" for systems that must deal with the natural world. It also teaches them that we sometimes need to make trade-offs in design. Yes, we can construct a culvert to make 99.9% sure that the road will be passable during even the largest of foreseeable floods, but is it really necessary for a gravel driveway on your neighbor's ranch? Whatever other benefits this approach produces, I consider it a success if, at the end of the semester, every student can correctly define a 100 year flood.

I imagine that teaching sustainability concepts may yield similar cognitive benefits. For instance, life cycle assessment requires a systematic style of thinking about the ultimate consequences of design decisions, while the triple-bottom-line approach forces the simultaneous consideration of multiple design objectives. Moreover, engineers addressing sustainability must tolerate ambiguous, often conflicting societal objectives and the possibility that an "optimal" solution may look different to all parties involved. I look forward to working on integrating sustainability into my courses and hope that this workshop will further my progress.

As for those irritated groundwater students, they eventually calm down…until we talk about karst!

Teaching Engineering Geology in a Geoscience Department

Robert Mitchell, Western Washington University

I'm pleased to have this opportunity to share specific examples of how I integrate engineering and geoscience in an engineering geology course I teach and explain why this is important for preparing students for the workforce. I will also present my vision for building on these successes, and, finally, discuss the challenges of integrating sustainability concepts into an engineering geology curriculum.

I've enjoyed teaching Engineering Geology (GEOL 314) in the Geology Department at Western Washington University (WWU) for the past 15 years. Because I have a science and engineering academic background, developing and teaching this course has been professionally gratifying. The course, fundamentally, focuses on the core activities of engineering geologists – site characterization and hazard identification/mitigation through the collaboration with engineers. Engineering geologists understand the complexities of natural systems and are adept at synthesizing detailed field observations into coherent inferences. They bring their geoscience approach to problem solving that is unique and complementary to an engineering methodology. Engineering geologists are applied geoscientists with an awareness of engineering principles and practice—they are not engineers. In states that require professional licensing (e.g., Washington, Oregon, and California) these practitioners become Licensed Engineering Geologists (LEGs), not Professional Engineers (PEs) like geological engineers and geotechnical engineers.

A key learning outcome of GEOL 314 is for students to understand the mechanics of Earth materials and how they respond to forces and stresses. Geology students have some basis of rock stress and strain from structural geology, but I advance their understanding in GEOL 314 by exploring in more physical detail the mechanics of rock, soils, and fluids, and how these relate to site vulnerabilities. Given that most civil projects are designed to function on the order of decades, students learn how to view 'sites' of rock masses and soil deposits as dynamic systems that may regress in response to changing internal and external forces during this time frame (not millennia). Like a classical geologist, an engineering geologist can analyze a structurally altered outcrop and hypothesize about its tectonic evolution, but, they are equally competent 'characterizing the site' as a rock mass that may fail and potentially cause harm to people and property. I have found that student understanding of these physical concepts improves with the application of numerical modeling tools. In GEOL 314 students use a software package developed by Rocscience, Inc.© to study rock and soil slope stability and settlement processes—the software is very effective for visualizing and examining the sensitivity of key parameters on these dynamic Earth systems.

Students also learn in GEOL 314 that they are part of a team of professionals and that technical information is shared using standard methods and conventions. The team can include engineering geologists, geotechnical engineers, structural engineers, architects, and government regulators. I teach students to collect, synthesize, and report geologic data and information using standards in engineering practice—standards such as those established by the American Society for Testing Materials (ASTM), the Unified Soil Classification System (USCS), and the International Building Code (IBC). I also advance this collaborative theme and classroom theory by promoting interactions with regional professionals and exposing students to the actual practice through case studies**.** We actively network with practitioners, both engineering geologists and geotechnical engineers, who visit campus to discuss their case study experiences, share data from projects, and participate on field trips. This professional development is also fostered by the Washington Section of AEG and WWU's AEG Student Chapter—we take trips to AEG meetings in Seattle to listen to case-study presentations and talk with practitioners; and occasionally participate on AEG sponsored field trips.

My approach in GEOL 314 is valuable for preparing students for the workforce because they can appreciate the connections and application of their academic training in addition to learning engineering fundamentals. Motivated by the success in this course, I have introduced engineering concepts into multiple courses within our Environmental and Engineering Geology concentration at WWU. Assessment evidence indicates that students value the topics and are learning, and, graduates are getting jobs. Among the BS geoscience degree granting programs in Washington, WWU has produced the highest percentage of licensed professional geologists in the state. Some graduates have gone on to get higher degrees in geological, geotechnical, and environmental engineering and are now successful practicing engineers.

The demand for engineering geologists in Washington State is growing. Population growth, development in challenging geologic terrain, forest practices, sea-level rise, geologic hazard mitigation efforts, and government policy are increasing the demand for Licensed Engineering Geologists (LEGs). Demand grows at the same time retirements of LEGs accelerate - 50% of the current LEGs in Washington will be retired in a decade. To help meet the demand for LEGs, and to continue to build upon my current engineering integration success, I am leading the effort to develop a BS degree in Engineering Geology at WWU. It is important to note that even though WWU does not have a civil engineering program with which to collaborate, I'm confident that the model of building engineering geologists within a geoscience program will be successful.

I am challenged, however, by how to better address the nontechnical aspects of sustainable development in GEOL 314 and my curriculum. Engineering geologists have great potential to be part of the solution in complex resource management and civil project decisions; so I also want them to think about economics, and resource and environmental impacts, and other concepts like ethics and leadership that embody sustainability. Regrettably, geoscience students do not have the necessary foundation for these ideas because geoscience programs do not explicitly address them—programs focus on teaching science—making observations and critical inferences under the umbrella of the scientific method. The challenge with integrating these sustainability concepts is comparable to teaching effective writing. Students need fundamental coursework in writing (sustainability) in addition to practice within the discipline. This is my goal—to impart nontechnical sustainability concepts in my curriculum to strengthen the voices of future engineering geologists in the sustainable development conversation.

Embracing the "Mess" in Environmental Systems

Kyle M. Monahan | Environmental Science and Engineering, Clarkson University

Geological problems such as those commonly found in the fields of environmental engineering and the geosciences are uniquely suited to an interdisciplinary approach. The environment itself is a highly complex system which consists of influences over wide spatial and temporal scales, which allows for the integration of many different ideas and concepts. The wide scope of environmental issues allows us to draw connections between many systems which at first glance would seem to be disparate; to embrace the "mess" of environmental systems.

Interdisciplinary Examples from Real Experience

Although the fields of environmental engineering and environmental science tend to ask different questions, they are two sides of the same coin. Environmental engineering is normally associated with the design and building of practical solutions to a problem, where environmental science aims to answer questions about why or how certain geological processes occur. In this way, the two fields can provide differing insights on the same issue. For example, say in an Oceanography class we begin to talk about the factors that create a tropical cyclone, and a student asks about Hurricane Sandy. The students can now learn about the mechanism behind the formation of tropical cyclones, as well as the engineering solutions designed to help cities cope with the destructive effects of such a hurricane. In turn, these topics can be related across disciplines to the economic losses from the storm, and even the lasting social effects which a storm has on a populace not acclimated to such a phenomenon. Providing such depth in specific examples is important to show the far reaching effects of systematic changes, and highlight the importance of the concepts involved. These real life examples bring relevance to the topics being studied, and also may garner more interest than only teaching conceptual hurricane formation dynamics without application.

Environmental Concepts & Mental Schemata

The experience of grappling with processes across large swaths of space and time can be a tough exercise for some students at the beginning of their education, but this can be made easier by the aforementioned cross-discipline examples. From a psychological standpoint, providing such an example allows for the formation of an organizational mental framework (commonly called a schema) under which to interpret other similar phenomena and allow for quicker categorization (Kastens, et al. 2006). For example, the principal of superposition, once learned can provide a framework for interpreting the age of fossil-bearing strata. When confronted with possible conflicting evidence from, for example a thrust fault where older layers seem to have been laid above those younger, this provides the opportunity for another framework to understand the new geophysical processes, or for further information to be added to the old schema to incorporate the new observation. Similarly, laboratory or field exercises are important as they add a hands-on experiential component to the schema formation; adding personal memories to solidify the applications of the concept. In the same way, thinking of sustainability in this context intrinsically adds a temporal component to such an example, asking "what will happen in the future; can this system endure?" These techniques of expansion of an idea over time and space are skills which are used by geoscientists and environmental engineers alike to make predictions, and in this way the "mess" in the environment can be thought of in terms of a small slice of a changing system through time and space.

Grappling With Real Data, Together

At the same time, just providing examples of a problem and a framework to refer to isn't always enough to teach the concepts at hand. For example, when teaching about air filtration methods for an environmental health and safety course, we talked about using a filter with a known flow rate of air past the filter, and being able to from there find the average concentration of a known mass of substance on the filter. However, these students clearly didn't really understand the concept until they had gone through the calculation and subsequent dimensional analysis, and actually collected dust with the filter. Dealing with the real environmental data provides practical skills which students need to know in the workforce and in graduate school, while bringing clarity to the possibly vague concepts discussed in class. This also explicitly outlines the "how" of drawing conclusions from a set of data, and allows for any confusion about the topics to be worked out by the student. For example, for a sedimentology course, the professor used a "do-talk-do" method of learning. The students would work with real data or modeling software, talk to each other about what they found and any problems they may have encountered, and then return to the data to draw conclusions and insights again, using the information they received from their classmates. The increased level of complexity and often large magnitude of data points provided to the students required the use of many of the basic science and math skills in drawing conclusions from the data, as students can be heard asking "what does this trend mean, though?" as they work through the tough task together. The connection to other previously learned concepts will make the new concepts learning easier to understand and more permanently learned. Also, this "data grappling" can outline problems and suggest solutions in a more accessible way than some conceptual models do.

Dealing with real environmental problems using actual datasets and examples is important as this is what students will have to do both in an environmental field, and doing so provides them valuable skills for their future. This also provides a framework for interpretation of wide-spanning, complex ideas while bolstering the structure with real life, relatable examples and data that the student can draw on as archetypical schema in the future. In general, the method of taking a conceptual model of a mechanism or problem to be solved and bringing it down to detailed examples across disciplines with real data that outlines those examples would enhance geological science and engineering education. Finally, providing ample space in the curriculum for inter-student collaboration builds upon the previous techniques to allow for even greater learning to occur.

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Dan Morgan

Teaching from multiple perspectives

"Like most North Americans of his generation, Hal tends to know way less about why he feels certain ways about the objects and pursuits he's devoted to than he does about the objects and pursuits themselves. It's hard to say for sure whether this is even exceptionally bad, this tendency."
- David Foster Wallace (1996)

"Crazy kids on the loose, but on the loose in the wilderness, and that made all the difference."
- Terry and Renny Russell (2001)

My approach to integrating engineering and geoscience is influenced by the above quotes, by David Orr's perspectives about teaching [e.g. "What is education for?" (1991) and "The problem of education" (1992)], and my training in geology and life cycle assessments. These influences help me think about issues on multiple timescales, to think about the role of humans in earth systems, and to consider the effects of these issues on real communities.

It is easy for a geologist to be flippant with the concept of sustainability. When viewed over the long term, we can recognize that people will not be able to "destroy" the planet, just as we will not be able to "save" it either. I suspect that many geologists would consider themselves environmentalists because we tend to value the natural world highly, but I think that many geologists would consider environmental issues to be mainly about self-preservation. Viewed in this light, pollution and over consumption are issues simply because we plan poorly for the long term.

The long-term perspective is something that I really appreciate in geology because it helps me think about the consequences of my actions past the here and now. But I often feel like it does very little to address the issues that need to be solved on shorter timescales to ease human suffering. My experience with life cycle assessments trained me to think about the consequences of our actions today, and how we can improve those impacts now to improve conditions. This training in engineering helps me consider how we design, build, use, and dispose of materials on a human timescale. To me, one of the important aspects of integrating engineering and geoscience is the blending of the timescales that we consider.

One of my favorite thought questions to ask my students in class is paraphrased from Robert Heinlein (1988): what's the difference between a dam built by a beaver for beaver purposes and a dam built by humans for human purposes. In my teaching, a fundamental goal of education is not simply literacy in a subject area; the goal is to become responsible citizens who will use their increased knowledge with an awareness of how it affects real communities. I am influenced by David Orr and the quotes above because I am concerned that students are too concerned with learning only what will be on the test, and not how this information plays out and affects communities. I believe it is important for students to understand that humans can affect earth's systems. This doesn't mean that I am trying to impart a certain morality upon my students, but that they do think about why they feel certain ways, that they look at issues from multiple perspectives, and that they learn how to think critically. Gaining perspective by getting out into the wilderness helps us consider the role that humans play in earth systems.

Dan Morgan

When I teach the introductory geology class, I am always trying to make sure that my students understand the applications of what we're learning so that they can see how it directly affects human lives. Many of my students will never take another science class, so it is imperative to me for them to recognize how science and engineering affect their daily lives. Thus, one of my teaching goals is that students who are successful in my classes know how to apply the scientific method to break down complex problems into measurable parts so that they can think of critical and creative solutions to any problem they may encounter in life.

I would like to incorporate more examples from contemporary life into my teaching so that I can demonstrate the impact of geology on our lives more acutely. This is where I can see a real need for me to learn more examples from engineering. In addition to the introductory geology class I teach, I also teach a structural geology course and it would be very useful to incorporate more examples of how materials break and deform from this literature. I think giving my students more examples from engineering would help them recognize the impact that these topics have on real communities.

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Incorporating engineering-based problem solving into water and environmental geology classes

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As a civil engineer teaching in a geology program for more than ten years, I integrate engineering into my geosciences classes regularly whether subconsciously or consciously. I find that as I'm developing my course material I ask myself how can I make this material relevant to my students and the answer is often to help them see how what they're learning about can be applied to solve technological, environmental and societal problems. In my classes I tend to focus on material and activities that are more quantitative, shorter-term process oriented, applied, problem-solving oriented and sustainability oriented.

The focus of my teaching is in water, environmental geology and environmental science, so incorporating engineering and problem-solving into my classes comes very naturally. Environmental geology is already what I call "anthropocentric geology", which makes the "how is it relevant to me" question very easy to answer and presents endless opportunities to demonstrate how basic scientific understanding can be applied to solve environmental and resource-related problems. In my water classes, since I was trained as an engineer, I tend to have a strong focus on problem-solving activities and exercises. I think that students obtain a deeper grasp and understanding of basic concepts when they successfully apply those concepts to solve problems.

One of my biggest challenges in teaching in a geology program is the lack of math preparedness of our students. Many struggle with basic algebra and I cannot assume that they've all had calculus by the time they take my classes. As a result, I have had to dramatically change the types of problems I assign, and to spend a lot more time on basic problem-solving skills. At the beginning of the semester in both ground water and hydrology I spend some time just talking about problem-solving and the steps to take when approaching a problem. I am very specific in my expectations for their homework assignments and work hard with many examples to help them understand that good problem solving takes practice and that taking their time and following some standard steps (e.g., writing the knowns and unknowns and drawing a picture before starting on the problem) can greatly increase their chances of success.

Along with the lack of math preparedness, I've also struggled with the students' lack of comfort with using quantitative tools like Excel. Over the years I have incorporated more exercises that teach basic quantitative skills. I schedule some class sessions in a computer lab and give them applied exercises to solve in Excel. I received a letter from a student after graduation thanking me for my classes and in particular thanking me for all of the Excel workshops because he felt that those skills helped him more in his job advancement than many of the other things he learned.

Another challenge is that I occasionally do get engineering students taking my hydrology class along with the geology and environmental science majors. Most of the engineering students have strong quantitative and problem-solving skills, but have had little, if any, exposure to the geosciences, sustainability and environmental issues. And, on the other hand, the geology and environmental sciences students often struggle with the quantitative problem-solving activities, but have a good understanding of earth-surface and environmental processes, landforms and issues. I do my best through the semester to help them feel good about their strengths and about learning in new ways that might push them in ways they haven't thought about before. In the future, I hope to incorporate group assignments and intentionally mix up the engineering students with the science majors.

I include engineering-oriented activities and perspectives in the following classes:

> **Basic Hydrology** – In this class, I present the basic science of the major hydrologic processes, but then go a step further and cover some basic methods of estimating and modeling each process. For each process, I present examples and problems that illustrate how our understanding of the process contributes to our ability to model the process. Then I try to give examples of how those results are applied. For example, Colorado agricultural water rights are based on the evapotranspiration (ET) rates of the crop that's being irrigated. So, after learning how ET works, they learn to apply the actual method that engineers use to calculate ET for agricultural water rights.
>
> **River Dynamics** – I teach this class more like an applied fluvial geomorphology class. I present the basic forms and processes of fluvial geomorphology, and then explore how those processes result in modern natural and human-induced channel changes and adjustments. I use a lot of local examples, but also take advantage of the opportunity to expose students to rivers and human impacts on rivers all over the world. In looking at human-induced changes we cover the impact of engineering on the natural environment, ensuing restoration efforts and how we can sustainably manage our resources. The students are required to do a small HEC-RAS modeling project on a stream reach that they survey in which they estimate the magnitude of a recent flash flood, and they also have to present a case study on a river that has undergone recent channel change.
>
> **Introduction to Ground Water** – I have two focuses in this class beyond conveying the usual course material. The first is to develop the students' problem solving and math skills. I've had students tell me after this class that they understand calculus better from this class than from their semester-long calculus classes. The second is to help them learn to write better technical reports. I require complete technical reports for three of their labs and spend a lot of time discussing the difference between technical writing and creative writing and why being able to clearly and logically communicate one's work is so important.

One of the things that I would like to try in all of my classes is to incorporate more student-centered active learning activities. I have attended teaching workshops offered at my university, but they have been more general and lacking in applications to the sciences or engineering. I've struggled with how to incorporate the things I saw at these workshops into my classes, for example, how to adopt a flipped classroom approach. In this workshop, I hope to learn new techniques for encouraging deeper-learning in my classes via more student-centric learning. Another goal that I have for this workshop is develop opportunities to engage engineering students in the geosciences.

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Engineering Hydrology with a Real-World Perspective

I regularly integrate engineering and geoscience in my junior-level Water Resources Engineering course which is required for all civil engineering undergraduates. Specifically, I teach students that they must understand the fundamentals of hydrology because the natural distribution of water, in both space and time, is the basis for design of water conveyance and storage facilities. Simply stated, the wrong amount of water is often in the wrong place at the wrong time. Water resources engineers must quantify the natural supply of water both spatially and temporally to design the man-made facilities that move it or store it for future use.

Engineering hydrology can be very formulaic – from use of design storms to synthetic unit hydrographs to simple rainfall-runoff relationships like the SCS curve number method and the Rational method. While it would be a disservice to my students to NOT teach them these fundamental techniques that underlie civil engineering design, I do not teach the procedural methods without first spending time teaching students about the spatially and temporally variable natural processes of rainfall and runoff generation.

My general approach to integrating these natural hydrologic processes and engineering design is to discuss current and recent hydrologic events – storms, floods and droughts – and their impact on society and the natural and built environment. I begin this approach on the first day of class by reading headlines from a stack of recent articles torn from the *New York Times*. These newspaper clippings are augmented by photographs and maps that I embed in my Powerpoint lessons throughout the term. During the first three weeks of this current term I have already had several opportunities to use Hurricane Sandy as the context for several hydrology and design lessons.

I carry this real-world link into homework assignments throughout the term. For example, rather than assigning a textbook problem about a generic "reservoir with a volume of x acre-ft" to the students for a mass balance analysis, I give students specific data about a real reservoir. A recent problem statement began as follows: "Lake Powell, located on the Colorado River upriver of the Grand Canyon, is the second largest reservoir in the United States. … At midnight on Jan 18, 2012, the water surface in Lake Powell was at an elevation of 3637.86 ft above MSL and the volume of water stored in the reservoir was approximately 15,752,000 ac-ft. Average inflows and outflows for the next seven days are tabulated below…" I follow up problems of this sort with photographs during lecture and with comments in later lectures and occasionally follow-up problems.

This approach of putting problems in a real-world context makes the problems more challenging, but also more representative of the types of analyses the students may need to do in their future careers. I provide students who are accustomed to cut and dry textbook problems that only give enough information to "plug and chug" in a single equation with the opportunity to answer questions that begin with the words "estimate" and "explain." These real-world problems also force students to grapple with the real-world uncertainty of some of the variables in an equation.

I also try to inform the students of the wealth of hydrologic data available from government agency websites. Every term I require students to download several days worth of real-time streamflow data from the USGS website and to discuss the shapes of the hydrographs in the context of what they have learned in class. I recently added a unit hydrograph assignment that uses real streamflow data from a local gaging station instead of "textbook numbers". The students see the date/time stamp of the data and need to search online for the watershed area to do their computations. Sending the students online to find hydrologic data will hopefully pay off when these students graduate because they will understand how to search for information needed to solve more open-ended problems.

I currently also integrate some aspects of geosciences in the GIS lab which I teach as part of our Introduction to Civil Engineering course. In the lessons about coordinate systems and map projections, students learn a bit about physical models of the three-dimensional earth. The assignments I give in this class can readily lend themselves to use of data from the fields of geosciences – like satellite imagery or soil types or hydrologic features – but unfortunately those assignments are still beckoning to be prepared. The students currently use census data to prepare most of their maps in this course because the data are readily available and easy to manipulate. A complete revision of the tutorial-based 6-week syllabus would need to be prepared. It would naturally be a real-world application in line with my approach in water resources engineering because the data that the students use would be drawn from real online databases. I see this as a positive direction because many civil engineering applications now rely on GIS for data management and visualization.

An unfortunate teaching impact of my use of this current events real-world perspective is that the need to constantly update my Powerpoint lessons with recent hydrologic events and to create new real-world assignments is very time consuming. Adding a geosciences-database-driven component to the GIS lab will add a similar level of increased preparation. But I hope it pays off by providing a better integration of the real geoscience data with engineering design, and with students who are better able to understand the naturally uncertain world.

It's a leucocratic gneiss. So what?

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"Fine, it's a leucocratic gneiss. So what?"

This statement captures the essence of my approach to integrating engineering and geoscience education. It was the catalyst for my gradual shift, one degree at a time, from geology, to engineering geology, to geological engineering. In fact, the fundamental differences between an academic approach to geoscience (the "scientist") and an applied approach (the "engineer") show up in other ways (Santi, 2009):

Scientist	vs.	Engineer
Why?	vs.	So what?
Descriptive	vs.	Importance
Understanding	vs.	Significance
Geologic maps	vs.	Derivative maps
Bedrock	vs.	Surficial deposits
Where are the outcrops?	vs.	How deep is bedrock?
What process created this?	vs.	Is it still active?
"Past oriented" model: present is the key to the past	vs.	"Future-oriented" model: recent past is the key to the near future

While these are extreme examples, they represent the ways that each group must learn to think in order to integrate skills from both ends of the spectrum. One category should not exist in the absence of its alter ego. With this in mind, I design classes to balance scientific discovery with practical application, to nurture engineering skills while establishing a knowledge base in geoscience. I approach this from the standpoint of injecting engineering thinking, tools, and problems into geoscience education. The reverse process is equally valid, but not one where I have as much experience.

Perhaps one of the most immersive ways to do this is to include larger design-based projects as part of the class. Examples might be "select a landfill site," "convert a quarry into a pond," "investigate a TCE plume," "map and rank geologic hazards in an area," "plan a scheme to stabilize a rock slope," "design a landslide drainage program," or "aesthetically stabilize a stream bank." Design in geoscience has some fundamental differences from classical engineering design (Santi, 2006):

- the solution not a widget (it may be a procedure, investigation, detection of something below ground, etc.),
- we work with materials not visible or homogeneous that are difficult to characterize,
- judgment and experience play a greater role, and
- the level of ambiguity is uncomfortably high.

Standard engineering tools can be used to address these unique components. For example, judgment can be made more objective by use of stochastic models, algorithms, or lumping of parameters. Ambiguity can be handled by presenting trade-off alternatives rather than numbers. Inhomogeneous materials can be appropriately described through sensitivity analysis, use of upper and lower bounds, and assessment of accuracy and error ranges.

Engineering can also be integrated through deliberate use of quantitative exercises, using real data, and asking open-ended problems. I am convinced that the lasting value of many of the math and engineering courses taken by geological engineers is not that they can solve triple integrals, but that they eventually turn into "numbers" people. Frequent use of quantitative data makes them methodical problem solvers, able to weed out bad information and communicate the process and the answers with clarity. Hand in hand with numerical data is the advantage of incorporating real data, which does not behave neatly and forces the use of higher intellectual skills (Bloom's levels of analysis, synthesis, and evaluation). Real data is also analyzed through the use of "war stories" in lecture, which teaches important engineering concepts of critical thinking and professional and ethical responsibility. Open-ended problems require integration of skills from across the curriculum, grappling with ambiguity and developing mature judgment. Engineering design problems are typically open-ended: they are incomplete, ambiguous, and self-contradictory, with no readily identifiable closure, yielding solutions that are not unique or compact, and they require knowledge from many fields (Hyman, 2003).

Like geoscience education, instruction in engineering requires a focus on communication skills through writing and technical presentations, as specified in ABET accreditation criteria for engineering programs. While proficiency in these areas is generally a goal, deliberate and focused scaffolding across the curriculum is a key to success, and I and others have published examples of strategies to do this (Leydens and Santi, 2006). The "ability to function on multidisciplinary teams" is also an ABET requirement, and this skill can be developed in the geoscience curriculum by dividing team projects into skill components (with different students responsible for expertise in structure, stratigraphy, Quaternary geology, or tectonics, for example), or by use of jigsaw learning and other methods that require resource and knowledge interdependence.

What I have touched on above is a broad range of ideas that represents curriculum-wide thinking. We explored the application of these ideas at the individual course and assignment level in a Journal of Geoscience Education paper (Santi and Higgins, 2005). In general, the integration of engineering skills and techniques into geoscience classes in this paper fell into five categories for implementation. First, short lecture asides or discussion problems in class give students immediate examples and practice applying their knowledge. For example, in the middle of a lecture on geomorphological analysis of hillslopes, I might explain how these techniques were incorporated into a debris-flow prediction model. Next, homework assignments provide a chance for focused application of learning: students can be asked to apply their latest knowledge to solve a real problem (e.g., "which weathering process led to settlement of a recent highway fill and how could it have been avoided?"). Third, application questions can easily be added onto mapping assignments. For instance, "identify and rank geologic hazards in the area," or "develop a cross-section at a specified depth where a tunnel is intended." Fourth, application questions can be added to laboratory exercises. Examples of these might include: "locate three water well locations where you expect the highest quality aquifer" or "evaluate rock mass strength and choose between two cross-sections for placement of high voltage transmission line towers." Finally, semester projects with primary focus on geoscience concepts can still include complex and multi-faceted questions related to site selection, material evaluation, and hazards analysis.

In summary, engineering education has some important connections with applied geoscience education. In engineering, there is an emphasis on application of knowledge. There is a sense of building towards a capstone experience – senior design classes for engineers, field camp and senior technical courses for geoscientists. Engineering focuses on capabilities and not just exposure to knowledge – e.g., what can you do with your knowledge? Finally, engineering relies on real-world examples and case studies.

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Teaching life cycle assessment (LCA) modeling through project based learning

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My approach to integrating sustainable engineering into the classroom at SDSM&T is through a life cycle assessment (LCA) modeling graduate class that I will teach Fall 2013 for the first time. I have previously incorporated LCA modeling as a module or component within a sustainable engineering course I developed (2009) and recently co-tough (2012) with a new colleague who was specifically hired to integrate sustainability into our Civil and Environmental Engineering curriculum. The course will be open to all students on my campus, which primarily consists of engineering and science majors. As a result, students may have a wide range of background and interest in this topic. Many of the students will be interested in integrating sustainability principles, and specifically LCA methodology, into their graduate research or within their engineering profession after they graduate.

The course will focus on the computational structure and data sources required to complete an environmental LCA. We will present, discuss, and apply LCA methodology to assess materials, products, and services from material acquisition through end-of-life. Assessments will identify opportunities for improvements on the basis of pollution prevention and resource conservation. As with most of the courses I teach, the course will be delivered using a project or problem based learning approach, utilizing many of the LCA modeling software available such as GREET (transportation sector biofuels; http://greet.es.anl.gov/), Earthsmart (web-based LCA model; http://www.earthshift.com/EarthSmartn that uses the Ecoinvent database; http://www.ecoinvent.ch/), Open LCA (free open-source LCA software; http://www.openlca.org/), and Sitewise (sustainable environmental remediation). Each of the projects will be completed within interdisciplinary teams where the students will work on an assigned or selected topic of interest, depending on the specific LCA modeling software we will be using at that point of the course. The goals of the projects are to further their understanding of sustainability and to encourage the students to effectively communicate their findings to a variety of audiences, whether to the public, policy makers, or campus colleagues.

I am looking forward to learning more about engineering and sustainability pedagogical techniques and sharing my classroom LCA knowledge.

Incorporating Environmental Issues Across the Curriculum

By Susa H. Stonedahl, Engineering and Physics, St. Ambrose University

Scientists study the world around them and try to understand how it works; geoscientists focus on the earth. Engineers design things to serve a purpose. We have been asked to write about approaches to integrating geoscience and engineering within our teaching. As I see it there are several ways that geoscience and engineering are inherently linked. One intersection of geoscience and engineering occurs when engineers literally redesign the topography of the earth: creating levies, straightening river channels, creating roads on or through mountains, making islands into peninsulas, etc. Another intersection occurs when engineers design means of removing materials found in the earth: coal, oil, gemstones, limestone, etc. All of these practices have been going on for a long time, but our ability to do them on a large scale continues to increase, as does our ability to measure the environmental impact of these actions. As a result, it becomes more and more important for us as a society to consider the consequences of these actions on the earth and on the people most affected by these actions. It becomes our responsibility to mitigate the damage done by previous generations and develop sustainable practices for the future. As educators it is important to pass this message along to the future engineers and geoscientists, as well as other majors that find their way into our classrooms, creating a more informed generation of global citizens.

My approach to integrating geoscience and engineering is to incorporate applicable sustainability and other environmental issues into each course. I believe environmental issues can be weaved non-disruptively into most classes and that this will have a greater impact than any single environmental course, as it will reach more of the student body and relate it to other areas of study. For instance, in my introductory physics classes I make a special point in the thermal conductivity unit to emphasize the purpose of insulation and how much energy is lost through single pane windows as compared to double paned windows. We use the continuity equation to calculate the amount of water flowing through an opening in the fluids chapter and consider the impact of a small flow like a leak over a long period of time. Simple choices of problems and their presentation can add an environmental flavor without deviating from the primary content of this course. I am also in the process of developing a natural science course focusing on rivers and streams, which will have a significant focus on preserving our water resources. We will touch on the positive and negative effects of locks and dams, a local feature for the students as our city (Davenport, IA) is on the Mississippi. We will also discuss the straightening of drainage ditches, which is another familiar feature of Iowa. Connecting the geoscience concepts to local features and geography should help the material seem relevant to the students. I will also be incorporating themes from my research on the region under a stream through which stream water flows (hyporheic zone), which acts as a filter for nutrients and pollutants. This will tie into the importance of developing sustainable agricultural practice in order to reduce the hypoxia in the Gulf of Mexico. Ideally all engineering and science courses would contain environmental elements and even many non-STEM courses like ethics and political science would incorporate some environmental discussion. I hope that by having environmental components, many of which integrate geoscience and engineering, in multiple courses it will help environmentalism become a part of the students' outlook and will influence their approach to solving real problems in their future occupations.

Finding a Global View at the Intersection of Geology and Engineering

by LeAnne Teruya

On January 12, 2010, Haiti was struck by a magnitude 7.0 earthquake that caused massive destruction and an astounding loss of 316,000 lives. Little more than a month later, an even larger, magnitude 8.8 earthquake struck off the coast of Chile, causing 550 lives to be lost. The consequences of Haiti and Chile earthquakes stand in stark contrast to each other. Each result was influenced by both the geology and the level of engineering each country requires for its infrastructure. This intersection between geology and engineering is a connection that forms a basis for integrating the two disciplines in my introductory geology course for civil engineers.

Geology and engineering both impact our lives everyday, but for the most part, the intersection of the two exists slightly below our level of consciousness. If we bring this connection into view, we will all have a more global view through which to approach the common goals of both fields (Fig.1). The case of the 2010 Haiti and Chile earthquakes is a good example of the intersection between geology and engineering. Geology and better building codes favored the outcome in Chile. In contrast, the close proximity of the earthquake epicenter to populated areas and the lack of engineering standards in Haiti produced an overwhelming loss of life and property. Studying examples that demonstrate the intersection between geology and engineering is a primary step in connecting these two fields.

Next, understanding how engineering and the geosciences intersect will help prevent manmade and geologically spurred problems by allowing engineers and geologists to do "pre-disaster" problem solving. This includes learning to predict areas at risk, and planning to prevent, minimize, or mitigate natural disasters. Knowing where faults lie and the type of rocks they cut through allows for structures to be placed away from the fault and be built to withstand the energy release expected from an earthquake near that location. Recognizing where past slope failures have occurred and where potential failures are likely to happen will likewise prevent structures, major throughways, and utility lines or facilities from being placed in those locations. Although we cannot predict when geologically triggered disasters will occur, we can identify the potential for these natural disasters and locations that will likely be affected by them. Geoscience and engineering knowledge combined will allow us to plan appropriately for the unexpected.

In my classroom, case studies offer a way to demonstrate the intersection between geoscience and engineering because they provide real world examples for students to examine. Every topic from rocks and minerals, to plate tectonics, to natural processes and disasters is tied to practical applications in civil engineering. Field trips illustrate where geology and engineering coexist and how both work together to resolve problems. We analyze the channeling of our local river, examine rock facades on buildings, and discuss the structural integrity of local buildings affected by an earthquake centered 48 miles away. To further encourage integration of the two fields, we could do more cross pollination: Allow geology courses to count as electives for an engineering major and allow engineering courses to count as electives for a geology degree.

The major benefit of integrating geology and engineering is that lives will be preserved and the effects of natural disasters will be prevented or lessened. We can start by finding connections between the two fields and focusing on the interface between the two disciplines. The knowledge exchanged will produce a more global view for reaching our common goals.

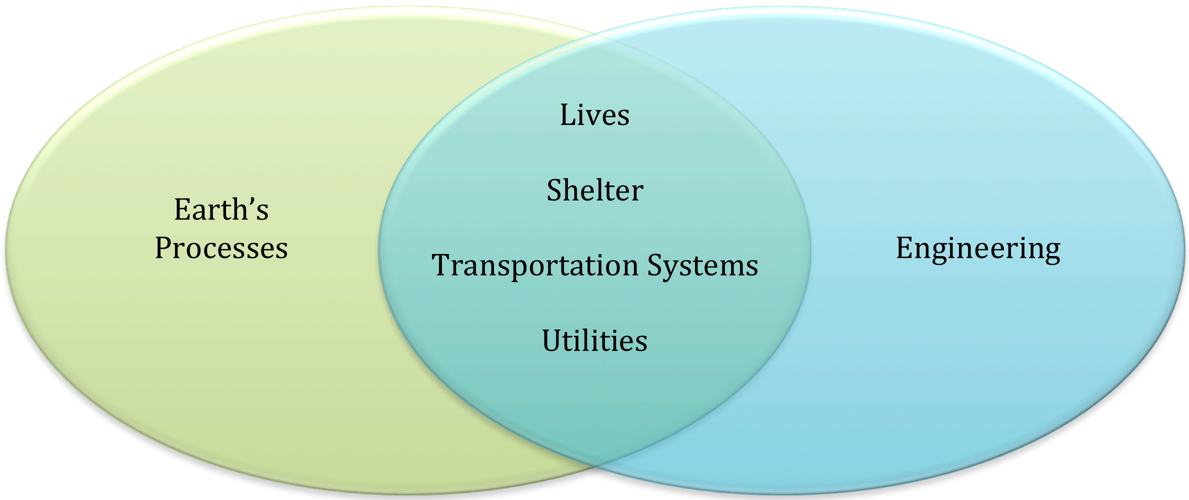

Figure 1. Geoscience and Engineering focus on the Same Goals. Geoscientists use knowledge of Earth's processes to protect lives, shelter, transportation and utility systems. Engineers design and build to reach the same goals.