Meeting the Grand Challenges: Developing Interactive, Earth Science Computer Simulations for Teaching Scientific Uncertainty

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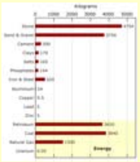
Introduction

This project seeks to prepare better future citizens, scientists and policy makers to deal with sustainability and grand challenges, i.e. sustainability and the grand challenges of energy, water, environmental change, land use modification and resource utilization and depletion, effectively and equitably, by improving their understanding of scientific uncertainty and its role in policy debates. To this end, computer simulations will be used to incorporate scientific uncertainty in proven case studies focused on sustainability and various grand challenges. Using simulations also allows these cases to be adopted in classes with variable enrollments, limited classroom instructor support and a variety of subject areas. The digital educational objects created and the computer guidelines and protocols established provide the conceptual and functional frameworks others can use to build their own simulations thereby expanding the case study catalog and discipline coverage.



Annual U.S. per capita resource utilization

The Grand Challenges

The German mathematician David Hilbert published a list of 23 unsolved mathematical problems in 1901 (Hilbert, 1901) and challenged the mathematics community to solve them. Over a century later, Hilbert's list has become the inspiration for the grand challenges, i.e. calls to spur progress toward solving important problems in a variety of disciplines. In a report on environmental sciences, the NRC (2001) defined grand challenges as "major scientific tasks that are compelling for both intellectual and practical reasons, that offer potential for major breakthroughs on the basis of recent developments in science and technology, and that are feasible given current capabilities, and a serious infusion of resources."

Although a precise, universal definition is lacking, grand challenges share some common characteristics including:

1) social relevance;
2) significant economic impact;
3) solvability;
4) the need for multidisciplinary approaches; and
5) required investment of significant resources.

Many of the grand challenge lists cite energy, water, environmental change, land use modification and resource utilization and depletion as particularly pressing issues facing humanity. To deal with these issues effectively and equitably, our nation, as well as the entire global community, will need a citizenry that is highly scientifically literate and capable of viewing problems from multiple perspectives.

Project Goals, Mechanisms and Objectives: Fostering Deeper Learning

Goals & Mechanisms

Goals: To prepare future citizens, scientists and policy makers to handle logically, effectively and equitably the complex, multi-faceted global problems humankind will face in the next century. These issues involve varying degrees of scientific uncertainty, i.e. a combination of complexity, heterogeneity, randomness and lack of knowledge. However, this concept is rarely or poorly presented in most undergraduate science courses, whether introductory or advanced. By creating a framework for developing, testing and disseminating computer simulations in Earth and environmental sciences, this project will permit instructors from a variety of disciplines to introduce their students to the role scientific uncertainty plays in understanding and solving the grand challenges as well as in scientific investigations in general.

Mechanisms:

- development of case study simulations focused on the grand challenges routinely reported in the media and professional literature
- exploration of scientific uncertainty in an active and engaging learning environment
- development of computer programming protocols necessary to build a computer simulation toolbox and engine

Objectives

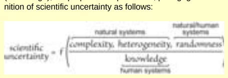
- Assemble a multi-disciplinary team to develop computer simulations
- Design, implement and test a Web-based Earth Science simulation toolbox/engine
- Computerize a petroleum exploration and assessment case study
- Computerize a gold prospecting and assessment case study
- Use computer simulations for student exploration of scientific uncertainty
- Produce learning materials to support instructor adoption and use of individual educational objects and computer simulations
- Develop and test assessment tools for measuring student learning through simulation-mediated instruction
- Evaluate the pedagogical effectiveness of the computer simulations
- Disseminate the two case studies, their learning materials and assessment tools to the Wyoming educational system (grades 9-16)

Project Timeline

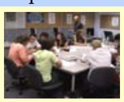
Scientific Uncertainty

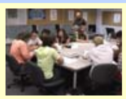
Resolution of any grand challenge requires integration of science, technology and society. Thus, multiple perspectives, e.g. scientific, political, economic, etc., must be reconciled to define the public policies. Each perspective is associated with an independent degree of uncertainty. Of these arguably the one that has been the most problematic in many debates is scientific uncertainty. Because many people view scientific knowledge as set, unchanging and absolute, they are confounded when faced with disagreement among scientists. Not surprisingly, scientific uncertainty has played an important and often negative role in many recent environmental debates. Clearly, to address the grand challenges, the general public as well as policy makers' understanding of scientific uncertainty must be dramatically improved.

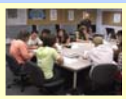
Scientific uncertainty is difficult to define precisely and with universal acceptance. Although definitions and taxonomies abound in the literature (Ascher, 2004), few provide the type of operational definition that is useful for crafting pedagogical approaches for bringing the concept of scientific uncertainty effectively into the classroom. Because the scientific uncertainty of a system is often related to its complexity, heterogeneity, randomness and how much is known about it (knowledge), we propose an operational, pedagogical definition of scientific uncertainty as follows:



Paper Simulations: Limitations







Logistic:

- spatial & temporal limitations on delivery
- instructor time sink during class
- extensive instructor/student interaction limits deployment to small enrollment classes
- difficult to modify for different student audiences, instructor goals or educational levels
- inflexibility limits development time & money impact

Conceptual:

- limited to overly simplified representations of natural/human systems
- cannot capture natural heterogeneity or randomness
- level of complexity that can be addressed is severely constrained
- student exploration is constrained, not open - confines inquiry

Case Studies

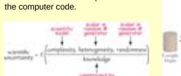
Case studies (or cases) are real or simulated stories or situations in which a central character faces a complex, ill-defined problem or dilemma. Based on the story, students must devise a solution(s) to the problem and identify the consequences of their solution(s). In this manner, cases build student confidence in dealing with the ill-formed and difficult problems of life as well as develop critical thinking and problem-solving skills.

Case studies are the centerpiece of the learner's laboratory experience in Myers' classes where they have replaced traditional paper and pencil exercises (Myers and Massey, 2006, 2008). Unlike most case studies (Herreid, 1994; 1997a; 1998), these cases place students in a variety of professional roles in organizations dealing with resource issues; e.g. an international oil company, an environmental group, a multinational mining company, a government bureaucracy, an environmental NGO, or a miner's labor union.

Resource	Country	Case Study	Modules
petroleum	Nigeria	Oil, Wealth & Conflict in Nigeria	I. Using Geology to Find Petroleum II. Is There Enough Crude to Produce? III. Wealth vs. Social Impact
	Saudi Arabia	Saudi Arabia, OPEC & Global Oil	I. Tapping the World's Largest Oil Fields II. OPEC & the Economics of Oil III. Energy Dependency: An OPEC Perspective
	United States	USA, Oil and ANWR	I. Understanding ANWR's Geology II. Getting ANWR's Oil to the Lower 48 III. Is ANWR the Path to U.S. Oil Independence?
coal	China	China, Energy and Kyoto	I. Planning Coal Lease Development II. Coal Power Plants: Maintain, Retrofit or Replace? III. Can Kyoto be Made to Work?
nuclear power	Iran	Power, Weapons & Iran	I. Designing a Uranium Mine II. Choosing a Reactor Design and Fuel Cycle III. Iran, the West and Nuclear Non-proliferation
biofuels	Brazil	The Future of Global Energy?	I. The Production of Biofuels II. Economic Reality: Biofuels vs. Petroleum III. Food vs. Fuel: The Global Implications of Biofuels

Programming

The ***conceptual framework*** for the simulations is based on our functional definition of scientific uncertainty. It illustrates the four dimensions of scientific uncertainty as well as the conceptual models we will use to express them in the computer code.



The ***functional framework*** for our simulations will bring together separate programming, modeling and customization threads.

Paper to Digital: Replacing A Paper Exercise with a Digital Simulation

Petroleum: Oil, Wealth & Conflict in Nigeria

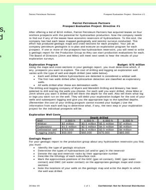
I. Using Geology to Find Petroleum

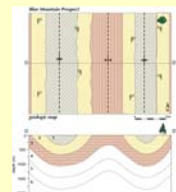
paper version: student packet

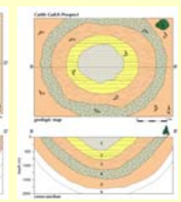
For module 1, each student group is given four potential hydrocarbon traps and an exploration budget. Using the geologic maps and cross-sections, they must design and conduct an exploratory oil and gas drilling program for each prospect. Depending upon their nature, e.g. wildcat, delineation, step-out, etc., wells cost different amounts to drill. Individual logs, i.e.gamma, neutron density, cost different amounts as well.

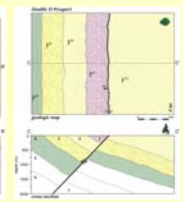
Geologic Tasks:

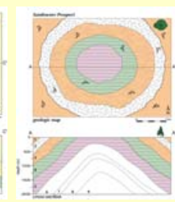
- identify geologic structures
- determine types of hydrocarbons
- denote cap and reservoir rocks
- mark GOC, GWC and OWC positions
- locate exploratory wells



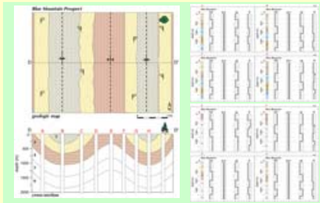


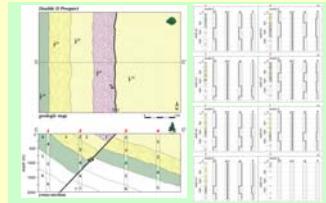




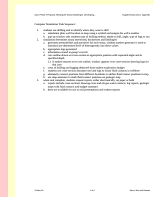


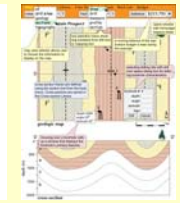
paper version: instructor packet





computer simulation





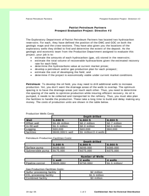
II. Calculating the Potential Value of a Hydrocarbon Reservoir

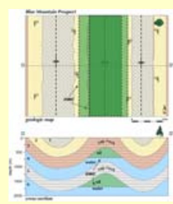
paper version: student packet

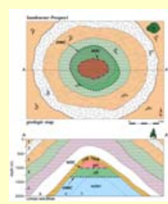
For the second module in the Nigeria petroleum case study, students perform an economic assessment of the two hydrocarbon reservoirs they found in the first module. They first estimate the volume of hydrocarbons in each reservoir and using market prices for the type of petroleum they have, estimate its value. Next they design an oil production program for each prospect. This entails converting exploration wells to production wells by casing them and installing production equipment. It also requires determining if additional production wells must be drilled and completed. By comparing the cost of their production plan against the value of the hydrocarbons, they can determine if the deposits are economically viable.

Economic Tasks:

- estimate recoverable hydrocarbons
- determine value at current market price
- develop hydrocarbon production plan
- calculate development cost
- make develop/no devlop recommendation







computer simulation