

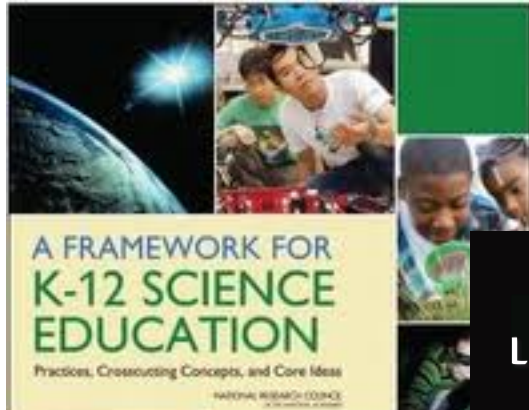
Models in Geoscience Education

Cathy Manduca

Director, Science Education Resource Center

Carleton College, Minnesota

Broad Interest in Models



EARTH SCIENCE LITERACY PRINCIPLES

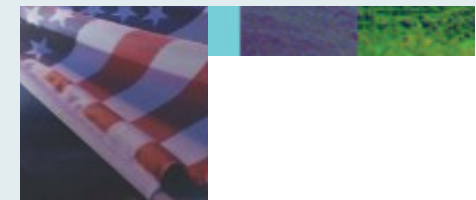
We consider eight practices to be essential elements of the K-12 science and engineering curriculum:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematical and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence

Challenge 1: understanding and forecasting the behavior of a complex and evolving Earth System



5% of workforce with highly leveraged impact



Workforce

Models in Undergraduate Geoscience Education

- ▶ Understanding the role of models in science – a case study
- ▶ Understanding complex systems – a world view
- ▶ Preparation for the workforce- a needed skill



The screenshot shows a website page with a header that reads "Bringing Research on Learning to the Geosciences". On the left is a navigation menu with items like "Geological Time", "Complex Earth Systems", and "Spatial Thinking in the Geosciences". The main content area features the title "Synthesis of Research on Thinking and Learning in the Geosciences" by Kim Kastens and Cathy Manduca. It includes a list of four themes: geological time, complex systems of the Earth, spatial thinking in Geosciences, and field-based learning. A "Related Links" box contains links to "Earth and Mind: the Blog" and "Private Site for Synthesis Participants". A footer note states the work is supported by the National Science Foundation (NSF).

Bringing
Research on Learning
to the Geosciences

Research on Learning
Synthesis Study
Geological Time
Complex Earth Systems
Spatial Thinking in the Geosciences
Field-Based Learning
Integrating Multiple Sources of Insight
Scoping Meeting
Journal Club
Writing Retreat
Browse Synthesis Resources
Share a Reference

Synthesis of Research on Thinking and Learning in the Geosciences

Kim Kastens, Lamont-Doherty Earth Observatory and Cathy Manduca, SERC, Carleton College, PIs

This project will synthesize existing knowledge and articulate unanswered questions in critical areas of research on cognition and learning relevant to the Geosciences. Geosciences encompass the study of the oceans, atmosphere, and solid earth, plus interactions between these physical systems and living systems. Within the domain of geoscience learning, our study will focus on four themes:

- [geological time](#),
- [complex systems of the Earth](#),
- [spatial thinking in Geosciences](#) and
- [field-based learning](#).

Each of these areas plays a central role in how human beings think about the Earth and learn to think about the Earth, and each poses substantial cognitive challenges. In addition, we seek to understand how geoscientists [integrate](#) these different types of learning in drawing inferences about the Earth.

The centerpiece of our work plan is to gather a small group of experts in geosciences, geoscience education, research on learning, and cognitive science at an isolated field station for a week-long learning/brainstorming/writing retreat. The writing retreat will be preceded by a smaller two-day planning and scoping meeting, at which we articulate major questions on each of our four themes, and identify a subset that have sufficient research base to be ripe for synthesis. Our findings will be disseminated through a suite of papers in a special issue of the Journal of Geoscience Education, on the widely-used "Teach the Earth" Web Portal, and in a journal that reaches the learning sciences community. This plan builds on four years of continuing effort to strengthen the cognitive and learning sciences research base underpinning geoscience education.

Join the conversation and discuss these and other related issues at the [Earth and Mind Blog!](#)

This work is supported by the National Science Foundation (NSF) under grant

Geoscience Perspectives

- ▶ Grounded in observation of the natural system
- ▶ Understood in the framework of a dynamic, complex Earth system
- ▶ Reflecting a long history of geologic time in which there are catastrophic events
- ▶ Geographically, spatially and temporally organized

Geoscience Strategies for Testing Hypotheses

- ▶ Studying a series of geographically or temporally specific examples to deduce underlying processes
- ▶ Developing multiple converging lines of incomplete data
- ▶ Testing understanding through prediction (models)

Learning about the role that models play in geoscience is part of understanding geoscience and a way to understand models more broadly

Learning Outcomes for Teaching About Models

- ▶ Models vs reality
- ▶ Understanding assumptions
- ▶ Testing results
- ▶ Uncertainty
- ▶ How to use results
- ▶ Role of models in science

On the Cutting Edge - Professional Development for Geoscience Faculty

Teaching with Data, Simulations and Models

Topical Resources

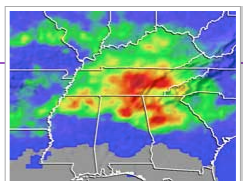
Cutting Edge > Teaching with Data, Simulations and Models

Cutting Edge

- Affective Domain
- ...click to see 6 more...
- Course Design
- Data, Simulations and Models**
- Sources of Teaching Materials
- Share Teaching Materials
- Classroom Activities
- Teaching Ideas
- Data Sets
- Tools
- Teaching Data and Simulations
- Pedagogy
- Worksheets
- Deep Earth
- Discover Mars
- Early Career
- Early Earth
- Embedding
- Assessment
- Energy
- Environment
- Geology

Teaching with Data, Simulations and Models

Today's geoscience education reaches beyond the traditional teaching tools such as rock samples and topographic maps. With the addition of computers in many geoscience classrooms and laboratories, faculty have unprecedented opportunity to create innovative learning experiences by bringing real-world data sets and models and simulations of geoscience processes into the classroom. This site provides resources to help faculty use



Torrential rainfall from a 2003 storm in the Southeast resulted in massive accumulations of rain (red).
Credit: NASA

Teaching Quantitative Skills in the Geosciences

resources for undergraduate students and faculty

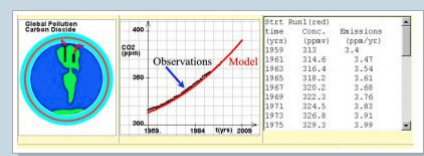
Search the Site Go

Quantitative Skills > Teaching Methods > Teaching With Models

- Quantitative Skills
- Issues and Discussion
- Teaching Methods
- Back of the Envelope Calculations
- Mathematical and Statistical Models
- Measurement and Uncertainty
- Metacognition
- Models**
- What is a Model?
- Why are Models Useful?
- How to Use Models
- Modeling Examples
- Teaching Quantitative Literacy
- Teaching Quantitative Reasoning with the News
- Teaching with Data
- Teaching with Data Simulations
- Teaching with Equations
- Teaching with SSAC
- Teaching Resources
- Settings
- Tools and Datasets
- Community

Teaching With Models

This material was originally created for [Starting Point: Introductory Geology](#) and is replicated here as part of the [SERC Pedagogic Service](#).
Created by Bob MacKay, Clark College



"Scientific practice involves the construction, validation and application of scientific models, so science instruction should be designed to engage students in making and using models." [Modeling Methodology for Physics Teachers](#) (more info) (1998)

What is a model?
Model Types: Conceptual, physical demonstrations, mathematical and statistical, and visualization.
This page briefly describes different kinds of models and provides links to more specific information about each of them.
[Learn more about the key features of different model types](#)

Why are models useful and important in Geoscience education?
Fundamental to science, great for interactive student-centered environment, ideal for a

Teaching Complex Systems



Inspiring Humility

- System is difficult to understand
- Impacts far from source in time and space
- Unanticipated consequences

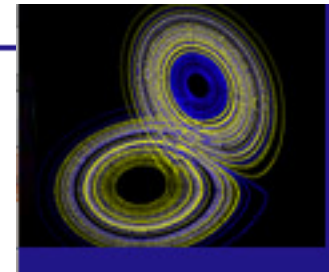


On the Cutting Edge

Professional Development for Geoscience Faculty

Developing Student Understanding of Complex Systems in the Geosciences

April 18-20, 2010
Carleton College, Northfield, MN



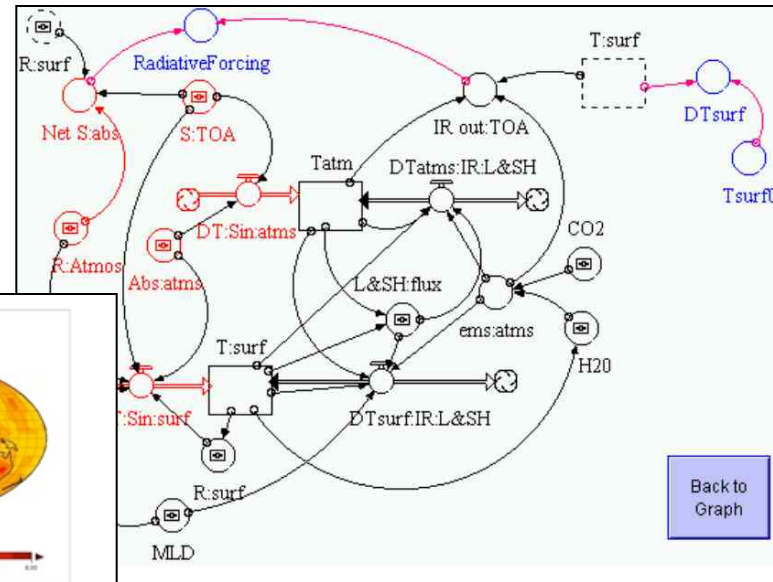
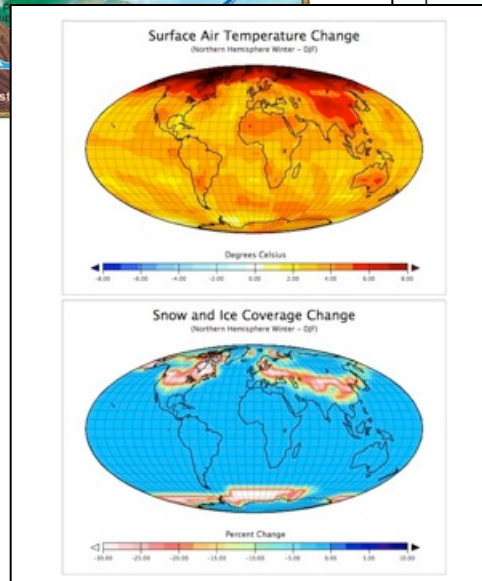
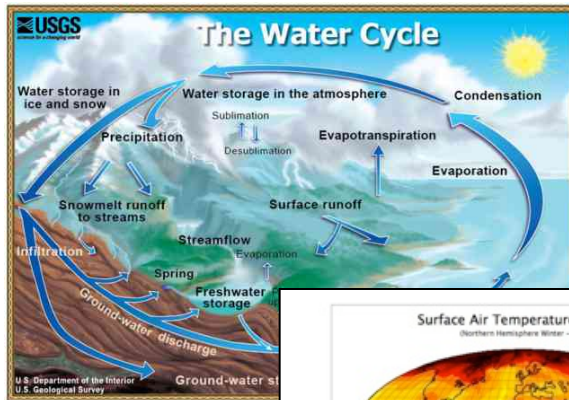
This workshop is for faculty who

- teach about or study complex systems, in the geosciences and in other fields such as science, economics, and engineering
- research the development of conceptual understanding of complex systems, or
- study the process of teaching or learning about complex systems.

We will bring together science educators, educational researchers, and cognitive scientists to share their understanding about successful strategies in teaching and learning about complex systems.



Understanding Complex Systems

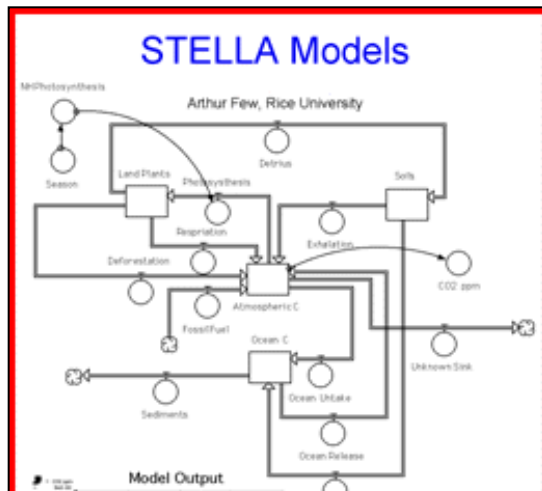
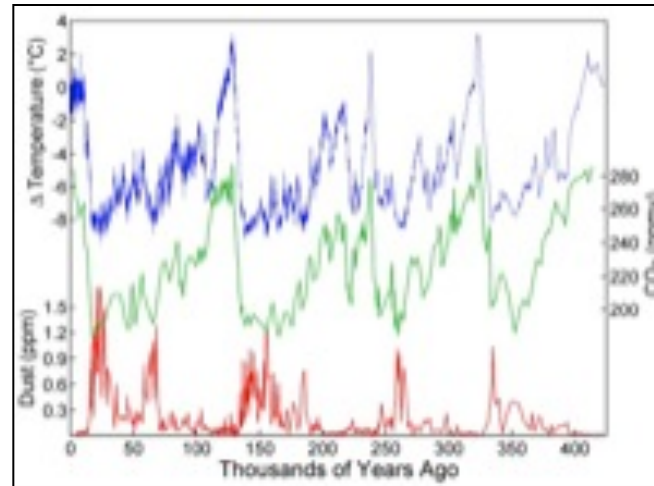


Takes time
Requires a K-16 Learning
Progression

Establishing a Learning Progression

- ▶ Ponds and glaciers are examples of a reservoir of water that has inputs and outputs and it is illustrative of a category
- ▶ Dynamic equilibrium in visible phenomena
- ▶ Generalizing ideas about stock and flows to include things you can't see, parallel stocks and flows with sediments
- ▶ Feedback loops- reinforcing and stabilizing
- ▶ Matter cycles create complex interactions that are sensitive to changes seeking dynamic equilibrium conditions over time

Understanding Complex Systems



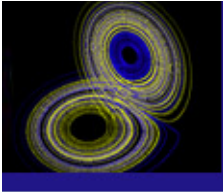
How do we recognize success?

Learning Goals

A student who demonstrates complex systems thinking can:

- Identify and explain the [characteristics of a complex system](#)
- Describe and/or model a process where there is a feedback mechanism at work
- Build a model that mimics the expected behavior of the target system
- Identify stocks/reservoirs and flows
- Correctly identify positive/negative feedbacks
- Test a model through trial and error and comparison to real-world data
- Explore the possible outcomes of a system under different parameters
- Bridge across scales: student explanations of processes show fidelity across scales (e.g., a student applies the concept of homeostasis at multiple levels)
- Create and interpret graphical information
- Predict attributes of system behavior based on specific inputs or components of the system
- Understand that a complex system is irreducible, unpredictable, historical, nonlinear, and has emergent properties, and be able to describe what these terms mean





Developing Student Understanding of Complex Systems in the Geosciences

Carleton College

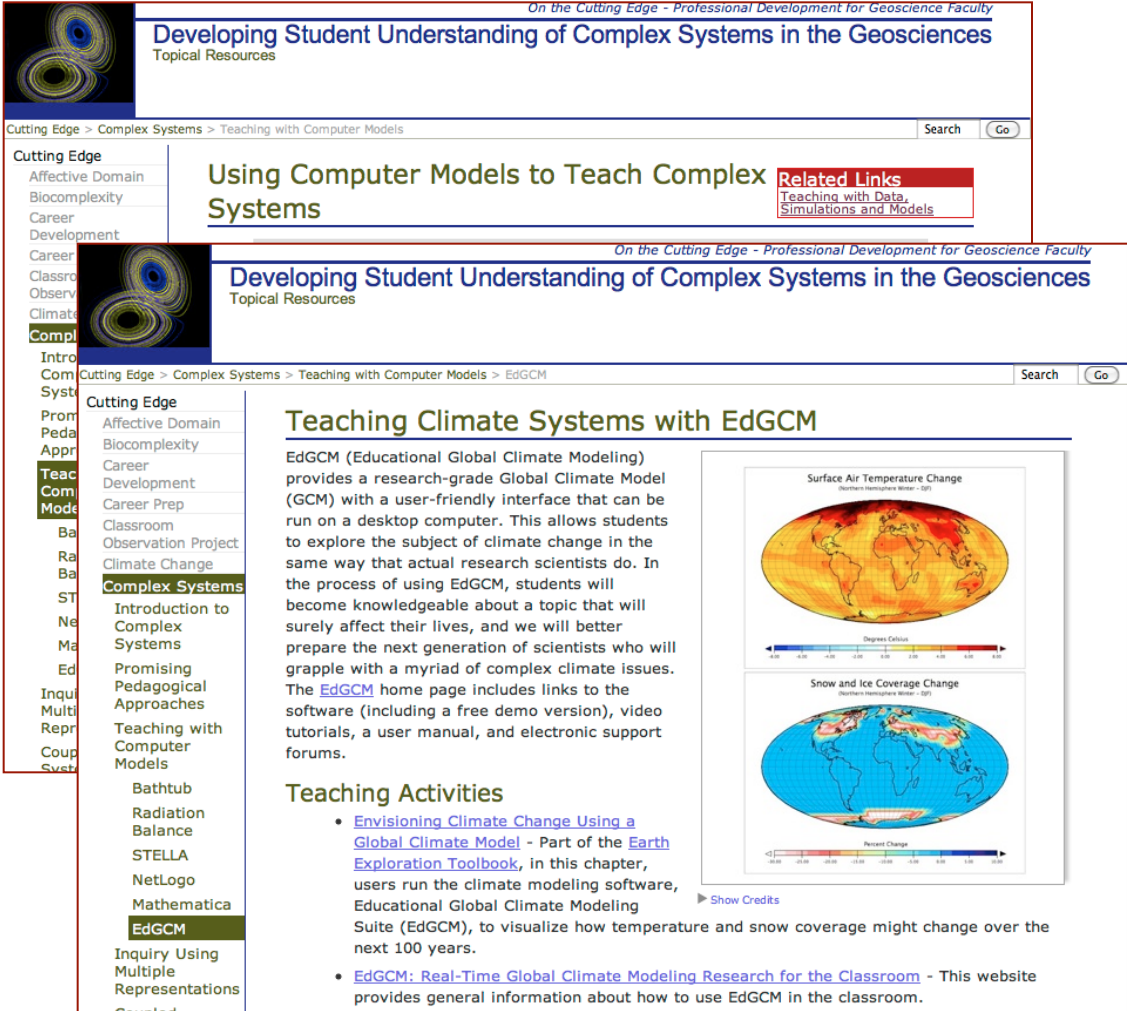
Some Challenges Inherent in Teaching about Complex Systems

Workshop participants identified the following key challenges they have experienced in teaching students about complex systems:

- Choosing where to begin. Do you start with the general characteristics of complex systems, before tackling specific examples? Or do you begin with a specific example, and use it to illustrate general characteristics? At what point do you define vocabulary terms, many of which will be unfamiliar?
- Asking students to deal with space and time scales beyond human experience.
- Complex causality (characterized by strongly interdependent variables, nonlinear interactions, and feedback mechanisms) does not mesh with cause-->effect understanding. Therefore, reductionist pedagogies -- looking for cause and effect relationships -- are generally not appropriate (Herbert, 2006). Breaking out of linear thinking patterns can be difficult for both students and instructors.
- Getting students to overcome the tendency to focus on "average" properties of a system. The non-Gaussian output distribution of complex systems makes average properties less likely than we are used to. Moreover, complex systems are rarely in equilibrium, so average properties may be even less applicable.
- Studying complex systems often requires an interdisciplinary approach.
- Biological evolutionary theory dominates as the only systematic mechanism for evolutionary change; self-organized criticality and emergence are unfamiliar concepts.

Models and complex systems

- ▶ Complex systems behavior
 - ▶ Feedbacks
 - ▶ Rates and lags
 - ▶ Emergent/unexpected outcomes
 - ▶ System intuition



On the Cutting Edge - Professional Development for Geoscience Faculty

Developing Student Understanding of Complex Systems in the Geosciences

Topical Resources

Cutting Edge > Complex Systems > Teaching with Computer Models

Search Go

Cutting Edge

- Affective Domain
- Biocomplexity
- Career Development
- Career
- Classroom Observation Project
- Climate Change
- Complex Systems**
- Introduction to Complex Systems
- Promising Pedagogical Approaches
- Teaching with Computer Models
- Bathtub
- Radiation Balance
- STELLA
- NetLogo
- Mathematica
- EdGCM
- Inquiry Using Multiple Representations
- Counted

Using Computer Models to Teach Complex Systems

Related Links

- Teaching with Data, Simulations and Models

On the Cutting Edge - Professional Development for Geoscience Faculty

Developing Student Understanding of Complex Systems in the Geosciences

Topical Resources

Cutting Edge > Complex Systems > Teaching with Computer Models > EdGCM

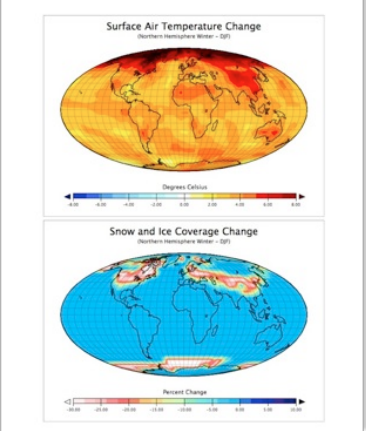
Search Go

Teaching Climate Systems with EdGCM

EdGCM (Educational Global Climate Modeling) provides a research-grade Global Climate Model (GCM) with a user-friendly interface that can be run on a desktop computer. This allows students to explore the subject of climate change in the same way that actual research scientists do. In the process of using EdGCM, students will become knowledgeable about a topic that will surely affect their lives, and we will better prepare the next generation of scientists who will grapple with a myriad of complex climate issues. The [EdGCM](#) home page includes links to the software (including a free demo version), video tutorials, a user manual, and electronic support forums.

Teaching Activities

- [Envisioning Climate Change Using a Global Climate Model](#) - Part of the [Earth Exploration Toolkit](#), in this chapter, users run the climate modeling software, Educational Global Climate Modeling Suite (EdGCM), to visualize how temperature and snow coverage might change over the next 100 years.
- [EdGCM: Real-Time Global Climate Modeling Research for the Classroom](#) - This website provides general information about how to use EdGCM in the classroom.



Surface Air Temperature Change
Northern Hemisphere Winter - 50Y

Degree Celsius

Snow and Ice Coverage Change
Northern Hemisphere Winter - 50Y

Percent Change

Show Credits



Rates, Dates and Geologic Time: Teaching about the Temporal Aspects of Geoscience

- ▶ Geologic Time Scale
 - ▶ Anchoring Events
 - ▶ Duration of Events
 - ▶ Rates of Processes
 - ▶ Uncertainty
-
- ▶ Relationships between space and time
 - ▶ Narrative and metric approaches
 - ▶ Visualiations

Workshop: Teaching About Time

February 26-28, 2012, at Arizona State University

Application deadline: January 2, 2012

Limited [stipends](#) are available to help defray workshop costs; the stipend application deadline will also be January 2, 2012.

Time and temporal concepts are critically important in a wide range of disciplines, from geoscience and other natural sciences to history and archeology. Students struggle with



On the Trail of Time at the Grand Canyon. Photo by Steve Semken.

rates and scales of processes that are beyond their personal experiences, with the complex interactions of slow processes over long time scales, and with the enormous numbers involved in Deep Time. A sophisticated understanding of these temporal concepts is an essential foundation for unraveling the complex histories of the Universe, solar system, and Earth; of species; and of civilizations. It is also key for contextualizing the natural and anthropogenic changes occurring on our planet today.

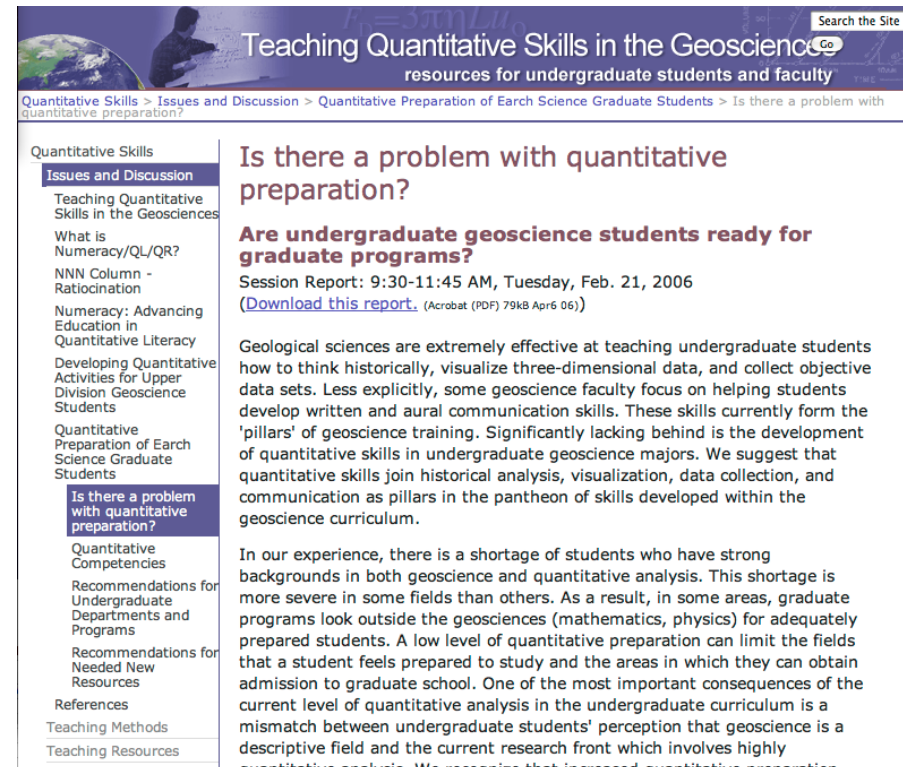
Join us for a workshop that will bring together faculty teaching about time with researchers studying temporal learning to

1. Understand current best practice in teaching about time,
2. Bring forward ideas from education and cognitive psychology that can inform improved practice, and
3. Work together in ways that support improved teaching about time.

Conveners

Preparation for the Workforce

- ▶ STEM students valued for quantitative and problem solving skills
- ▶ Geoscience research requires the capability of working with quantitative data and models
- ▶ Geoscience employers value quantitative skills
- ▶ From Wall street to Washington the workforce needs to know more about models and complex systems



Search the Site

Teaching Quantitative Skills in the Geosciences

resources for undergraduate students and faculty

Quantitative Skills > Issues and Discussion > Quantitative Preparation of Earth Science Graduate Students > Is there a problem with quantitative preparation?

Quantitative Skills

- Issues and Discussion
 - Teaching Quantitative Skills in the Geosciences
 - What is Numeracy/QL/QR?
 - NNN Column - Ratiocination
 - Numeracy: Advancing Education in Quantitative Literacy
 - Developing Quantitative Activities for Upper Division Geoscience Students
 - Quantitative Preparation of Earth Science Graduate Students
 - Is there a problem with quantitative preparation?**
 - Quantitative Competencies
 - Recommendations for Undergraduate Departments and Programs
 - Recommendations for Needed New Resources
- References
- Teaching Methods
- Teaching Resources

Is there a problem with quantitative preparation?

Are undergraduate geoscience students ready for graduate programs?

Session Report: 9:30-11:45 AM, Tuesday, Feb. 21, 2006
[Download this report.](#) (Acrobat (PDF) 79kB Apr6 06)

Geological sciences are extremely effective at teaching undergraduate students how to think historically, visualize three-dimensional data, and collect objective data sets. Less explicitly, some geoscience faculty focus on helping students develop written and aural communication skills. These skills currently form the 'pillars' of geoscience training. Significantly lacking behind is the development of quantitative skills in undergraduate geoscience majors. We suggest that quantitative skills join historical analysis, visualization, data collection, and communication as pillars in the pantheon of skills developed within the geoscience curriculum.

In our experience, there is a shortage of students who have strong backgrounds in both geoscience and quantitative analysis. This shortage is more severe in some fields than others. As a result, in some areas, graduate programs look outside the geosciences (mathematics, physics) for adequately prepared students. A low level of quantitative preparation can limit the fields that a student feels prepared to study and the areas in which they can obtain admission to graduate school. One of the most important consequences of the current level of quantitative analysis in the undergraduate curriculum is a mismatch between undergraduate students' perception that geoscience is a descriptive field and the current research front which involves highly quantitative analysis. We recognize that increased quantitative preparation

Questions?

On the Cutting Edge - Professional Development for Geoscience Faculty


Teaching Sedimentary Geology in the 21st Century

Topical Resources

Cutting Edge > Sedimentary Geology > Teaching with Physical Models

Using Physical Models to Teach Sedimentary Geology

by Thomas Hickson, University of St. Thomas

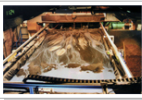


Physical models have formed the basis for numerous classic ideas in sedimentary geology, from G.K. Gilbert's first flume experiments to full-scale sedimentary basin-filling models at the St. Anthony Falls Lab and elsewhere. Physical models can be used to develop fundamental intuition about sedimentary processes, quantitatively constrain sedimentation rates, and test numerical models of sedimentation. In sedimentary geology courses, physical models can serve as the basis for short, in-class demonstrations or for full-blown course projects.

[Learn more about why to teach with physical models](#)

Projects and Exercises

The Experimental Earthscape Facility (XES basin)



This experimental facility can simulate the fundamental controls on sedimentary basin fill and provides insight into how sedimentary basins evolve over geologic timescales and respond to external forcings.

Cutting Edge

- Affective Domain
- Stratigraphic Up Indicators
- Sedimentary Geology
- Using Physical Models
- Why Teach with Physical Models?
- Experimental Earthscape Facility (XES)
- Videos and Images
- The Desktop Delta
- Annotated Bibliography
- Workshop 06
- Service Learning
- Spatial Thinking
- Structural Geology
- Student Learning: Observing and Assessing
- Teaching Methods
- Urban Geology
- Visualization
- Web-Based Resources

- ▶ Google search terms for resources
 - ▶ SERC Cathy
 - ▶ SERC guide data teaching
 - ▶ Teaching complex systems
 - ▶ Cutting Edge time rates
 - ▶ Teaching Quantitative Skills Geoscience

