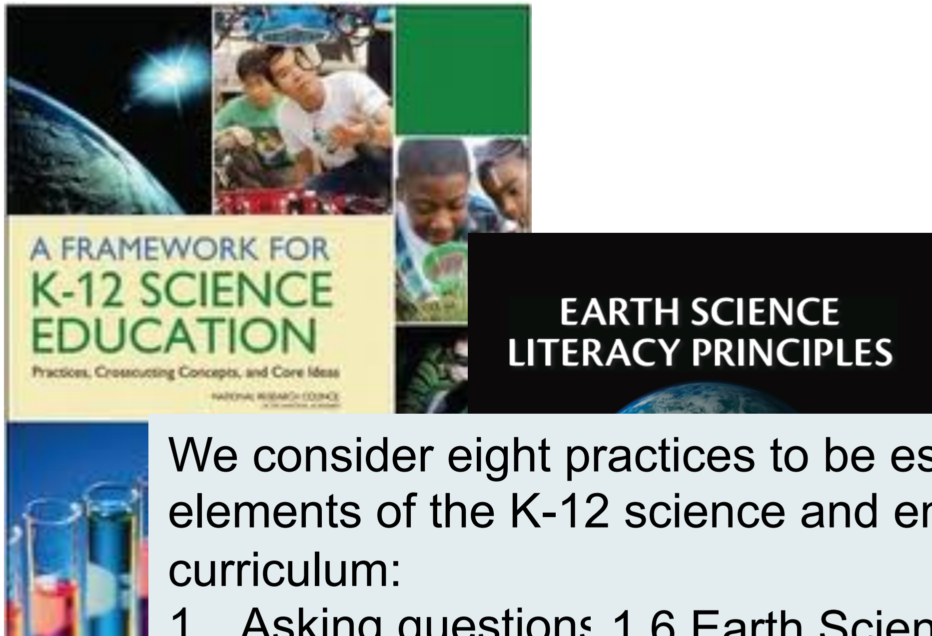
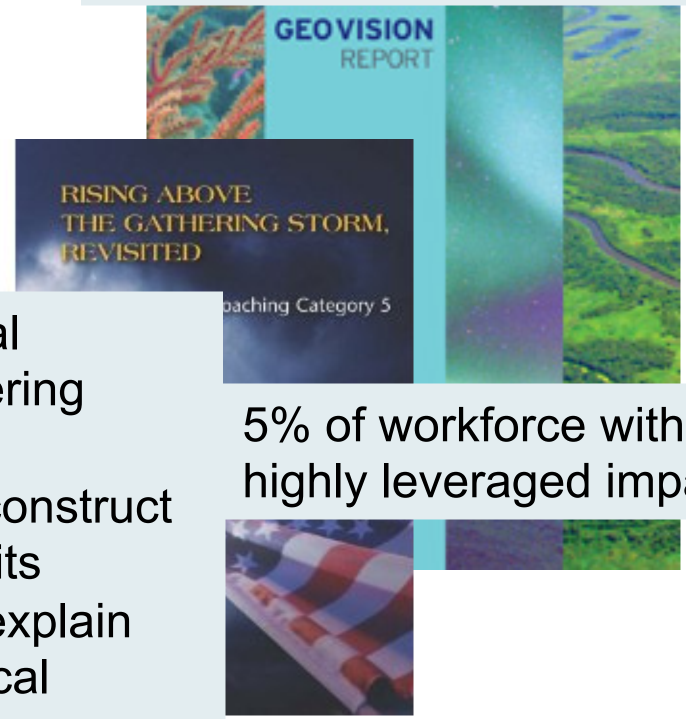
Models in Geoscience Education

Cathy Manduca
Director, Science Education Resource Center
Carleton College, Minnesota

Broad Interest in Models

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





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

1. Asking questions
2. Developing and
3. Planning and ca
4. Analyzing and in
5. Using mathemat technology and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence

1.6 Earth Scientists construct models of Earth and its processes that best explain the available geological evidence.

5% of workforce with highly leveraged impact

E

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

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

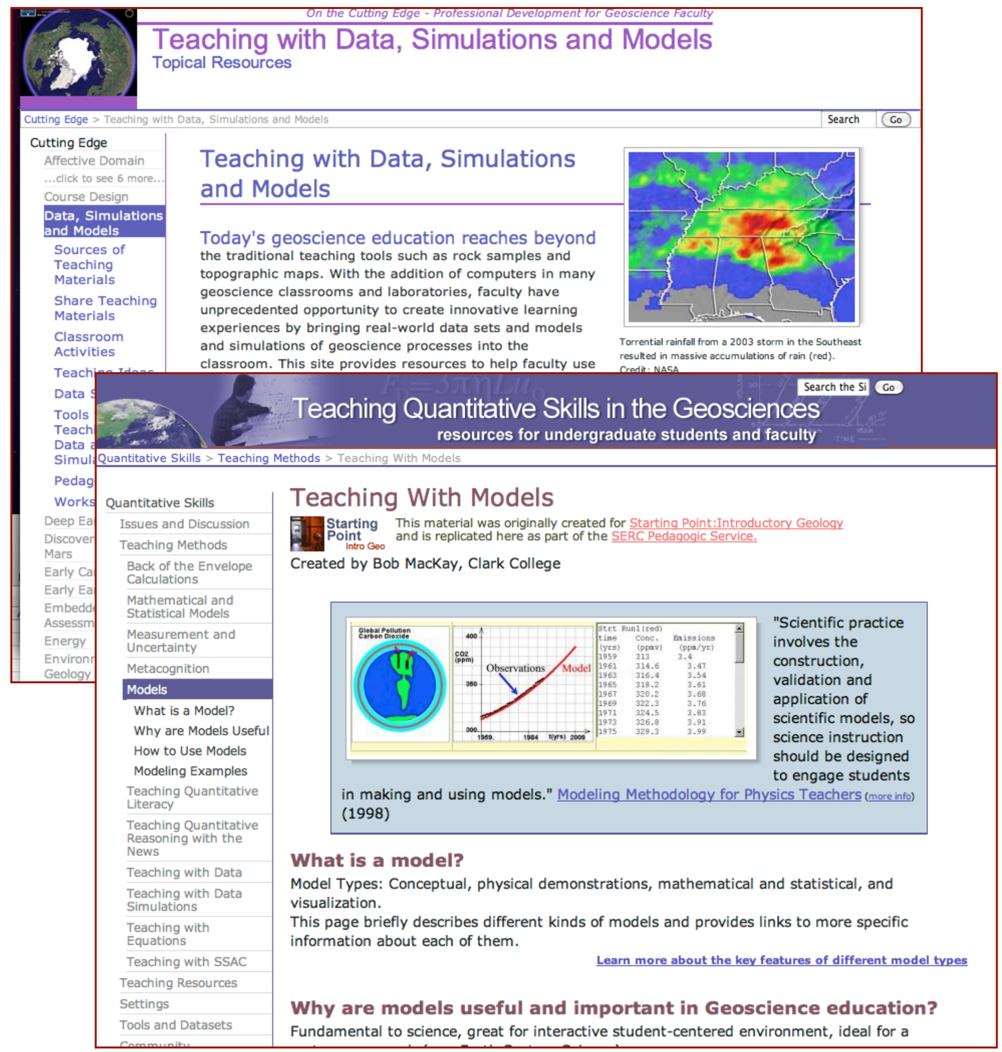
Geoscience Strategies for Testing Hypotheses

- 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

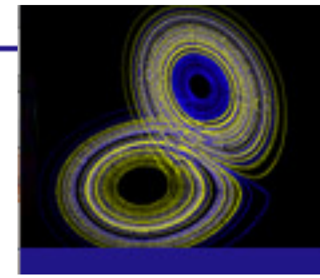


Teaching Complex Systems

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



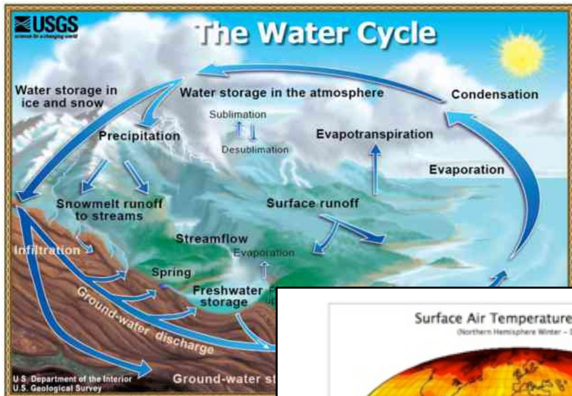
April 18-20, 2010
Carleton College, Northfield, MN

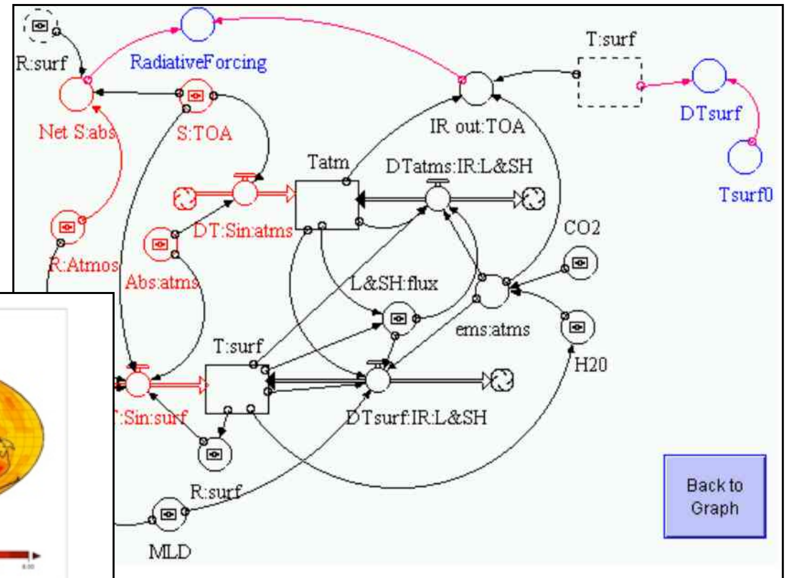
This workshop is for faculty who

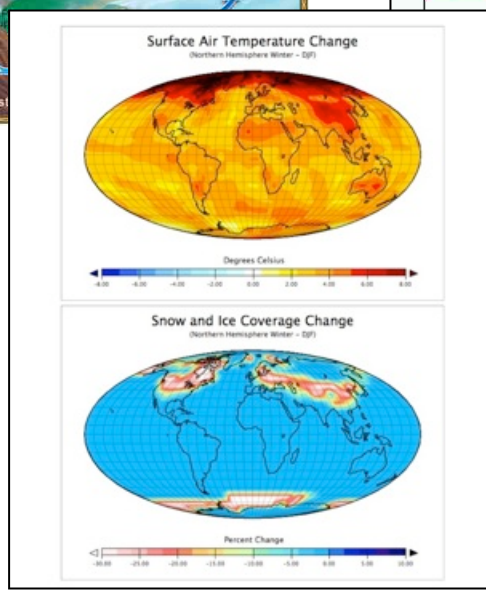
- teach about or study complex systems, in the geosciences and in other fields such as science, economics, and engineering
- research the development of conceptual understanding of complex systems, or
- study the process of teaching or learning about complex systems.

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







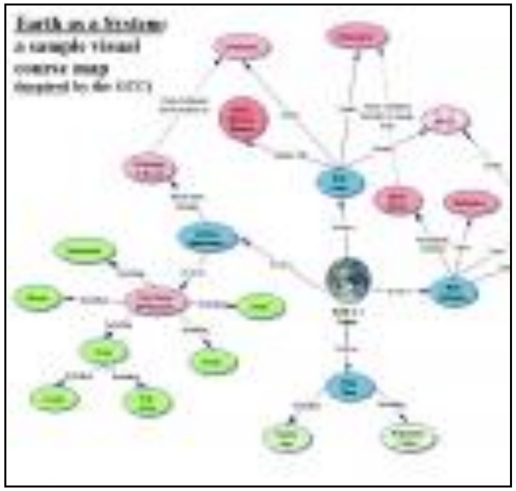
Takes time

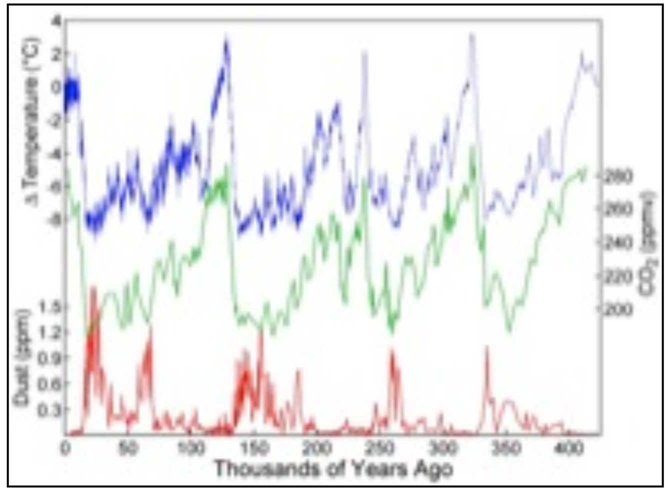
Requires a K-16 Learning Progression

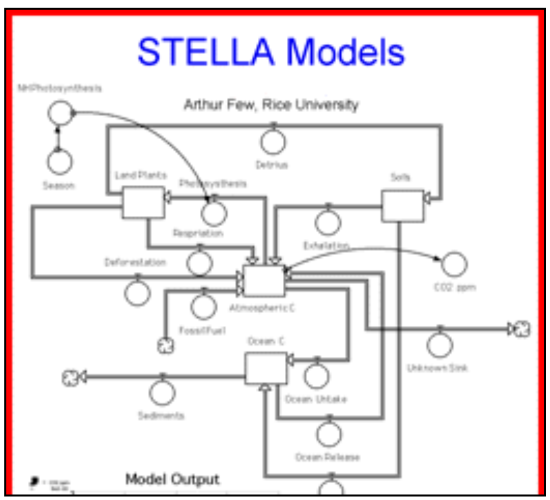
Establishing a Learning Progression

- 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

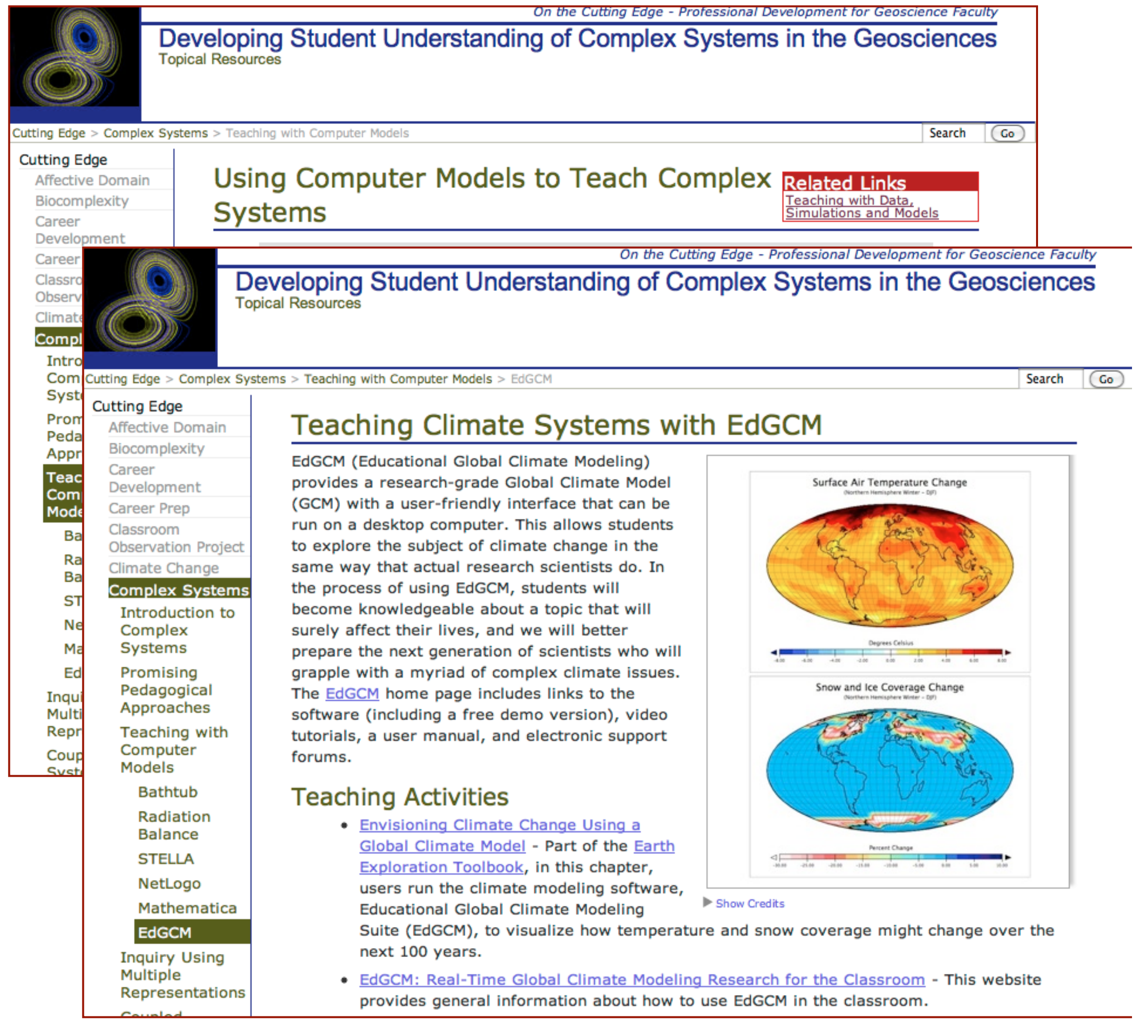
Some Challenges Inherent in Teaching about Complex Systems

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

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

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

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 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.

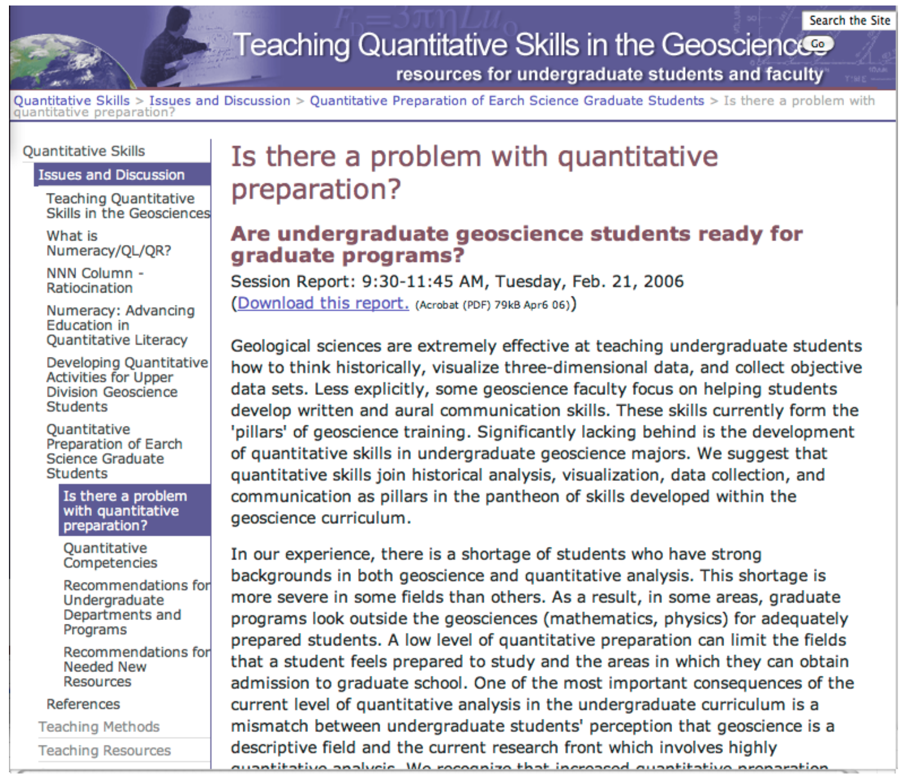
Join us for a workshop that will bring together faculty teaching about time with researchers studying temporal learning to

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



Teaching Quantitative Skills in the Geosciences

resources for undergraduate students and faculty

Search the Site

Quantitative Skills > Issues and Discussion > Quantitative Preparation of Earch 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 Earch 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?

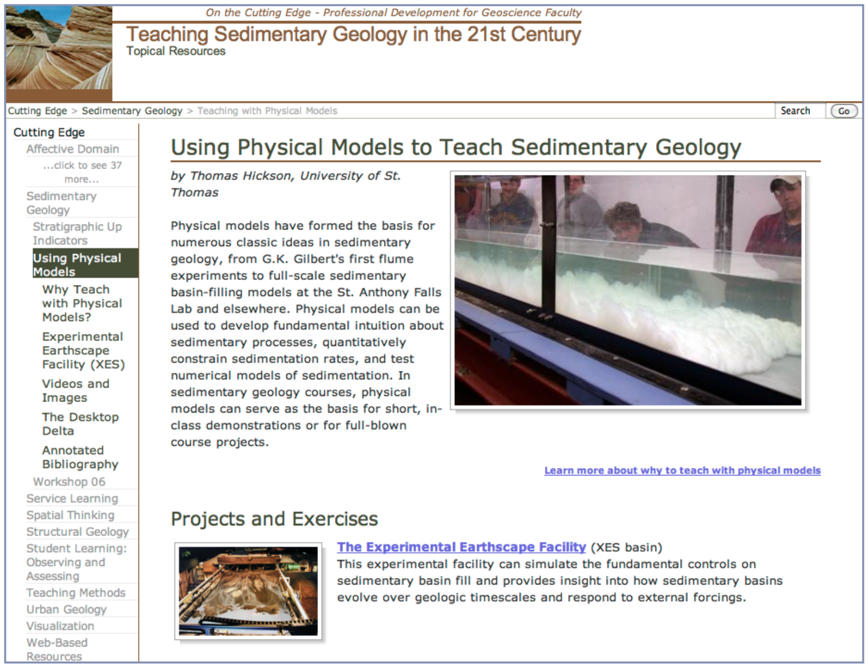
Are undergraduate geoscience students ready for graduate programs?

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

Questions?



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

SERC the Science Education Resource Center at Carleton College