Undergraduate Earth System Science Education

NSF, CC, EV, ESS, POGIL & STELLA too...

Howard Drossman
CMMAP Team Meeting
New York University
January 6, 2009
Outline

• **CC-CMMAP Education & Diversity Initiatives**

• **CC-Earth System Science (ESS) Curriculum**

• **Undergraduate ESS Classes**
  - EV 128: Introduction to Global Climate Change
  - EV 211: Human Impacts on Biogeochemical Cycles
  - EV 431: Air-Atmospheric Physics & Chemistry

• **What’s Next?**
  - Enhance the web of connections
  - Focus on modes of inquiry
  - Teach about paradigms
  - Design and implement useful assessments
  - Disseminate classes and strategies
CMMAP Education & Diversity Initiatives

- Improve undergraduate Earth Systems Science and climate education.
- Teach next generation of leading climate scientists to be better teachers.
- Improve the retention of women in the science and engineering “pipeline” from middle school through graduate school.
- Improve recruitment of under-represented groups into Earth Science at the undergraduate level.
Educational Objectives Integration

- YES Students & K-12 Students
- Teachers & K-12 Teachers
- CC Professors
- CMMAP Research Scientists
- CMMAP Grad Students
- CC Students
- YES Students & K-12 Students
- YES Teachers & K-12 Teachers
CC-CMMAP Funded Grad & Faculty Activities

Graduate Student Teaching Mentorships

• Luke Van Roekel (EV 431-07): Drossman
• Jim Benedict (EV 431-08): Drossman
• Kate Thayer-Calder (EV 128-08): Leonard
• Kelley Wells (EV 431-09): Drossman
• Rachel McCrary (EV 128-09): Taber
• Anna Harper (EV 128-09): Fricke

Faculty Visits (CC Seminars & Class Visits)

• David Randall (2007; EV 431)
• Scott Denning (2008; EV 128)
• Jeff Collett & students (2008; EV 431)
CC-CMMAP Funded UG Students

Annual student scholarships, 2008:

Alice DuVivier & Jette Petersen: Laplacian operators (Randall)
Tyler Ruggles: Community GHG Reduction Strategies (Betsill)
Zoe Keve: Biomass Fuel Policy (Kathlene)-Thesis
David Sullivan: Carbon Pricing Policy (Kathlene)-Thesis
Brittany Vogel: K-12 Education (LSOP, NCAR, Catamount)
Sarah Waldo: BEACHON (NCAR/Drossman)-Thesis
Summer Roberts: BEACHON (NCAR/Drossman)
Rich Brereton: EV 431 Assistant-Grad School, Ecosystems

Annual student scholarships, 2007:

Rebecca Simpson (Kreidenweiss): Atmospheric Science, U Hawaii
Parker Kraus (Denning): Atmospheric Science, CSU
Gillian Bobier (NCAR, Catamount): K-12 Education?
Beth Beckel (Collett): Grad school?
CC Graduate Student Mentors

• Barb Whitten (Physics)
• Mike Taber (Education)
• Matt Reuer (Environmental Science)
• Raj Pandhya (NCAR)
• Sally Meyer (Chemistry)
• Eric Leonard (Geology)
• Miro Kummel (Environmental Science)
• Steven Janke (Math)
• Henry Fricke (Geology)
• Howard Drossman (Environmental Science & Chemistry)
Our Education Mission:
Inspire the Next Generation of Earth System Scientists
“Earth System Science courses are distinguished from Earth Science courses through their explicit multidisciplinary focus on the connections, interactions and feedbacks between the system components: atmosphere, hydrosphere, lithosphere, biosphere, anthroposphere, and exosphere.”

*Science Education Resource Center at Carleton College: http://serc.carleton.edu/introgeo/earthcoursedesign/whatis.html
Colorado College Environmental Program

Environmental Science
Environmental Science-Physics
Environmental Science-Chemistry
Environmental Policy
LAS Major in Environmental Science
Environmental Issues Minor
Environmental Program
Discipline-Based Classes

- Global Destiny
- Politics
- Philosophy
- Religion
- Social Processes
- Human Activities
- Sociology
- Medicine
- Technology
- Agriculture
- Engineering
- Industry
- Terrestrial Ecosystems
- Tropospheric Chemistry
- Marine Biogeochemistry
- Atmospheric Physics/Dynamics
- Terrestrial Surface Moisture/Energy Balance
- Stratosphere/Mesosphere Chemistry
- Solar/Space Physics
- Biology
- Ecology
- Oceanography
- Geology
- Meteorology
- Chemistry
- Physics
- Mathematics
Lower Level ESS Classes

EV 128: Introduction to Global Climate Change (no pre-reqs)

Calculus 1

EV 211: Human Impacts on Biogeochemical Cycles
Upper Level ESS Classes

EV 212: Energy
Environmental Thermo & Dynamics

EV 311: Water
Hydrology, Aquatic Chemistry & Ecology

EV 431: Air
Atmospheric Physics & Chemistry
Three-Year Capstone Sequence

EV 221
Environmental Inquiry (Sophomore)

EV 321
Environmental Management (Junior)

EV 421
Environmental Synthesis (Senior)
Some Key Questions:

• How do scientists deal with uncertainty?
• Does science provide the “correct” answers?
• How do scientists reach a consensus?
• What can science provide to policy makers?
• What ethical issues relate to climate change?
Introduction to Global Climate Change

- 4-5 sections/year
- 16-25 students/class
- ~50% by gender
- ~10% minority
Systems Modeling with STELLA

Linear Steady State System

Nonlinear System
No Atmosphere STELLA Model

- Initial temperature
- Solar constant
- Albedo
- Depth of mixed layer
- Heat capacity
- Temperature
- Sigma
- Specific heat of water

Diagram:

- Solar
- Energy
- IR
- Heat capacity
- Density of water

Graph:

- T Celsius
- Years

Legend:

- Solar constant
- Albedo
- Depth of mixed layer
- Heat capacity
- Temperature
- Sigma
- Specific heat of water
- Density of water
EV 211
Human Impacts on Biogeochemical Cycles

Some Key Questions:

• What is a model?
• How is feedback incorporated?
• What is the sensitivity of different variables?
• How do we evaluate the quality of data?
• Why do some systems display complex behavior?
• Are we living in the Anthropocene?
EV 211
Human Impacts on Biogeochemical Cycles

- Two blocks/year
- ~16 students/block
- EV/Policy majors
- EV 128/calc pre-req
"Shoebox" Energy Balance STELLA Model

Ocean Flux → Water in Air
Evaporation → Humidity
Sat Humidity → Cloud Sat Humidity
Mass Air → Cloud Capacity
Temperature → Ocean Water
Ocean Water → Precipitation

Cloud Flux → Cloud
Condensation → Cloud

Evaporation → Latent Heat
Conduction → Heat Capacity

Sun → Energy
Temperature 2 → Energy

Evaporation → Conduction
Evaporation → Latent Heat

Heat Capacity → Cloud Temp
Delta T Cloud → Cloud Temp
Area Cloud → Cloud Temp
Cap Air → Cloud Temp
V diffuse → Air Density
Air Density → Cap Air

1: Water in Air
2: Water in Ocean
3: Energy

0.0004 0.80005 1.1e+06
0.0002 0.7998 1e+06
EV 431: Air
Atmospheric Physics & Chemistry

Some Key Questions:

• How do we model the weather?
• Should Colorado College move its Children’s Center to a larger site closer to the interstate highway?
• Why does ozone chemistry appear to change in different regions of the atmosphere?
EV 431: Air
Atmospheric Physics & Chemistry

• 1 block/year
• ~20 students/block
• EV, EV-Physics & EV-Chem
• POGIL Approach
Atmospheric Dynamics STELLA Model

Run # | Latitude
-----|---------
  1  | 0.00
  2  | 20.0
  3  | 40.0
  4  | 60.0
  5  | 90.0

Graph showing the relationship between latitude and some variables.
What’s Next?
Strengthen Ties with Leverage

- CMMAP Research Scientists
- Undergraduate Students
- Grad Students
- Undergraduate Professors
- Informal Ed & K-12 Teachers
- K-12 Students
Teach science as we do science
1. Compare the Equator-to-North Pole $T$ gradient in January to the Equator-to-South Pole $T$ gradient in July. Which is stronger? In which hemisphere is the Equator-high latitude $T$ gradient more dependent on the choice of longitude? Why?

2. Using the set of equations in Model 1 and your answer to Model 2 Q2, describe the wind aloft (tropopause) in terms of speed, direction, and overall how wavy the flow is.

3. Would you expect any motion from the troposphere to the stratosphere (vertically) over the winter pole? Why or why not?

4. Based on your responses to the questions in Model 1 and Model 2, in their respective winters, do you expect the Arctic or the Antarctic to be more isolated from the rest of the Earth? Why?
Using the Research Literature as an Educational Tool

- Literature vs. Textual Readings
- Literature-based exams
- POGIL literature-based exercises

Representative Papers in EV 211:


Earth Systems Science Education: Transdisciplinary or Multidisciplinary?

<table>
<thead>
<tr>
<th>I</th>
<th>IT</th>
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<tbody>
<tr>
<td>Ethics</td>
<td>Mathematics</td>
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<tr>
<td>Cognition</td>
<td>Physics</td>
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<tr>
<td>Metacognition</td>
<td>Chemistry</td>
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<tr>
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<tr>
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<td>Oceanography</td>
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<tr>
<td>Religion</td>
<td>Political Science</td>
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<tr>
<td></td>
<td>Atmospheric Science</td>
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<td>Terrestrial Biogeochemistry</td>
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### Transdisciplinary vs. Multidisciplinary Learning

<table>
<thead>
<tr>
<th>Interior</th>
<th>Exterior</th>
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<tbody>
<tr>
<td><strong>Individual</strong></td>
<td><strong>Collective</strong></td>
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<td><strong>Interior</strong></td>
<td><strong>Exterior</strong></td>
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<tr>
<td><strong>What inspires me to learn?</strong></td>
<td><strong>What are simple observable behaviors?</strong></td>
</tr>
<tr>
<td>Motivation, Metacognition</td>
<td>Observations, Hypothesis testing</td>
</tr>
<tr>
<td><strong>What inspires us to learn?</strong></td>
<td><strong>What are complex observable behaviors?</strong></td>
</tr>
<tr>
<td>Peer learning (POGIL), Science as cultural paradigm</td>
<td>Human systems dynamics, Earth systems dynamics</td>
</tr>
</tbody>
</table>
Kuhn’s Scientific Paradigms

Unexplained Phenomenon

Current Paradigm

Problem!
Answers Don’t Make Sense

New Paradigm

Scientific Revolution

Adapted from: Thomas Kuhn, *Structure of Scientific Revolutions*
OH WOW!
PARADIGM SHIFT!
Science can be thought of research, while paradigms are used by to along with shown as circles. This allows the position of each paradigm to be codified and available for lookup, for instance Fluid Mechanics paradigms are in grid B3.

We have also calculated and displayed the vitality of each paradigm. Vitality is a measure of the speed at which a group of researchers reaches consensus about major improvements. Paradigms are constantly being improved, but it usually takes years to reach consensus about which improvements are major. The white circles represent communities where consensus is reached relatively slowly. This is a common phenomenon in the social sciences, ecological sciences, computer sciences, and mathematics disciplines. The red circles represent communities of researchers where consensus is reached relatively rapidly. This is more common in physics, chemistry, biochemistry, and many medical disciplines. Very dark circles (such as those in Astrophysics, LS-5) represent communities where consensus is reached extremely quickly.

The map of scientific paradigms and its reference system can be used for multiple purposes. Countries, industries, companies, universities, and individual researchers can all locate themselves within the map, either as single points, or as a specific collection of paradigms. Various metrics, such as vitality, can be overlaid on this reference system to highlight specific impacts. Science education and personal discovery can also be enhanced by linking stories and facts to the map that highlight scientific history, current advances and relationships between scientific paradigms.
Design and implement assessments

- SALG Assessment
- ACS Exams
- Project-based assignments
- POGIL
- Literature-based evaluations
- Demographic Surveys
- Tracking student interns
## EV 221 Assessment Example

### EV 211 ACS Exam Results

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Prior Chemistry</th>
<th>No Prior Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual Test</td>
<td>69.8%</td>
<td>62.5%</td>
</tr>
<tr>
<td>Standard Test</td>
<td>67.8%</td>
<td>51.1%</td>
</tr>
</tbody>
</table>

- **p = 0.142**
- **p = 0.009**
EV 221 assessment example

Pre-Test Correlation

$y = 7.8898x + 19.813$
$R^2 = 0.605$

$y = 6.7281x + 31.493$
$R^2 = 0.473$

Quiz Score vs. Pre-Test Score graph with two linear equations and their $R^2$ values.
Disseminate Classes & Strategies

WHAT
• POGIL Atmospheric materials (JAMES, Web)
• Research literature-based POGIL materials
• Graduate student mentoring
• Pedagogy
• Assessment strategies and results
• Classes

HOW
• Web
• JAMES, BAMS articles
• Workshops (PKAL, CUR, SENCER)
Video Games: A Route to Large-Scale STEM Education?
Merrilea J. Mayo

Video games have enormous mass appeal, reaching audiences in the hundreds of thousands to millions. They also embed many pedagogical practices known to be effective in other environments. This article reviews the sparse but encouraging data on learning outcomes for video games in science, technology, engineering, and math (STEM) disciplines, then reviews the infrastructure obstacles to wider adoption of this new medium.
Undergraduate ESS Curriculum Development Summary

1. Understand the mission—inspire ESS students
2. Identify target audience and needs—undergrads
3. Establish curricular goals—ESS interest/understanding
4. Evaluate existing curricular material—GCC/BGC Cycles
5. Assess students' prior knowledge—POGIL/ACS Exams
6. Match pedagogy to generative questions—STELLA/POGIL
7. Teach & evaluate with formative assessment—POGIL
8. Summative assessment—SALG, Literature, ACS Exams
9. Incorporate new findings (go to step 3)
10. Disseminate curriculum