Learning Theory and Practical Lessons from Experiences in Science Education Reform

Cherilynn A. Morrow
Professor of Physics & Astronomy
(education focus)
STEM Director
Georgia State University

Aspen Global Change Institute Workshop:
Global Change and the Solar-Terrestrial Environment
Session H: Education and Public Outreach
Aspen, CO
15 June 2010
The Joy of Solar Physicists in Science Education

Cherilynn A. Morrow
Space Science Institute, Boulder, CO

34th Meeting of the Solar Physics Division  Laurel, MD  June 2003
WELCOME to the Workshop on Science Education

by
Dr. Cherilynn A. Morrow
morrow@spacescience.org

In support of the pioneering collaboration between the Haas Center for Public Service and the Solar Physics Group at Stanford University
Video: A *Private Universe*

- Write down 3 key messages or ideas that you take away from the *Private Universe* video
I taught Stripe how to whistle.
I don't hear him whistling.
I said I taught him, I didn't say he learned it.
• Why didn’t the lessons on seasons and lunar phases get through to Heather?

• What are the preconceptions that interfere with Heather’s ability to get the fundamental concepts of why there are seasons or why there are moon phases?
“Students enter the classroom [and audience members enter the auditorium] with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught…”

Learners of all ages hold prior ideas about the world around them that can interfere with scientifically correct understanding. Good science instruction allows people to express, confront, and resolve these ideas.

Learners are not blank slates!

“Rain comes from clouds sweating.”
A Child’s Mind at Work on Rain and Clouds (W.C. Philips)

• Rain comes from holes in clouds.
• Rain comes from clouds sweating.
• Rain falls from funnels in the clouds.
• Rain occurs when clouds get scrambled and melt.
• Rain occurs when clouds are shaken.
• God and angels cause thunder and lightning.
• Clouds come from somewhere above the sky.
• Empty clouds are refilled by the sea.
• Clouds are formed by vapors from kettles.
• The sun boils the sea to create water vapor.
• Clouds are made of cotton, wool, or smoke.
• Clouds are bags of water.
Prior Knowledge is derived from “Phenomenological Primitives”

Andrea diSessa (1983)

- When children touch something on the stove, they learn that temperature increases with decreasing distance.
- When children hear a car’s horn, they learn that sound intensity increases with decreasing distance.
- When children see a bright flashlight, they learn that brightness increases with decreasing distance.

⇒ CLOSE MEANS MORE

a rule we internalize and use to keep us alive

C. A. Morrow & T.F. Slater camorrow@colorado.edu tslater@as.arizona.edu
• So what type of teaching is consistent with research on how people learn?

• What type of teaching promotes deeper conceptual change and understanding rather than superficial and ephemeral memorization?
The Monotillation of Traxoline

It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is monotilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then bracter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescelidge.

Directions: Answer the following questions in complete sentences.

1. What is traxoline?
2. Where is traxoline monotilled?
3. How is traxoline quaselled?
4. Why is it important to know about traxoline?

Attributed to Judy Lanier
The Monotillation of Traxoline

It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is monotilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then bracter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescelidge.

Directions: Answer the following questions in complete sentences.

1. What is traxoline?
2. Where is traxoline monotilled?
3. How is traxoline quaselled?
4. Why is it important to know about traxoline?

Attributed to Judy Lanier
What Happens If We Teach by Telling?

Research shows that students memorize what they are told for the test, but then:

- revert back to original ideas, OR
- develop two knowledge schemes: “book knowledge” and “real-world knowledge”, OR
- alter what they hear to fit their old knowledge scheme, *but rarely will they realign their conceptions of the world*

C. A. Morrow & T.F. Slater camorrow@colorado.edu tslater@as.arizona.edu
HAS THIS EVER HAPPENED TO YOU?

DeLaughter et al., "Preconceptions Abound Among Students in an Introductory Earth Science Course", EOS Transactions AGU, Volume 79, Number 36, 8 Sept 1998
Conceptual Change Model

1. The student must be dissatisfied with a currently held conception.

2. The student must understand an alternative conception. (It has to be intelligible.)

3. The student must believe that this alternative conception is plausible.

4. The student must see how using this alternative conception could help to solve problems or answer questions. That is, the alternative concept should be fruitful.

   Posner, Strike, Hewson, & Gertzog, 1982
Learning Cycle - OPERA

- O for Opening – engage interest, open inquiry
- P for Prior knowledge discussion (predictions)
- E for Experiment or Experience
- R for Reflection on how the results of the experiment has influenced prior knowledge
- A for Assessment and Application of what is learned to a new inquiry

15 June 2010
C. A. Morrow
cmorrow@gsu.edu
HAS THIS EVER HAPPENED TO YOU?

DeLaughter et al., "Preconceptions Abound Among Students in an Introductory Earth Science Course", EOS Transactions AGU, Volume 79, Number 36, 8 Sept 1998
Doing Science: Teaching Science

**Science Process**
- Raise fundamental question of interest
- Research what is already known
- Plan & implement experiment
- Reflect on results and how they affect what was known before
- Communicate learning via talks & papers – invite peers to apply and assess.

**Learning Analog**
- Engage students, OPEN inquiry
- Assess PRIOR knowledge of students
- Plan & implement a hands-on EXPERIENCE
- REFLECT on results and how they affect prior knowledge
- APPLY and ASSESS learning. Communicate learning to teacher & student peers.
Modern Science Education Reform

- Students as “scientists” with teachers as facilitators of learning
  - Teacher as “a guide on the side” rather than a “sage on the stage”.

- “Inquiry-based” process of learning
  - “The way scientists do science rather than the way they were taught science.”

15 June 2010
C. A. Morrow
cmorrow@gsu.edu
DESIGNING LEARNING ENVIRONMENTS BASED ON CORE PRINCIPLES OF HOW PEOPLE LEARN

Uncover **preconceptions**. Meet learners where they really are instead of where you think they should be.

Promote **comfort with questioning**, revealing thoughts, co-creativity, willingness to struggle. Reduce pressure to know it all. Link to life.

Give **conceptual framework** for facts & ideas to facilitate ability to retrieve and apply knowledge to new situations: ‘Learning with understanding’ rather than rote memorization of stray facts. Learners see same concept in different contexts. Less is more.

Cultivate **metacognitive skills** so that learners become more self-aware when they “get it” and when they don’t. Make learners’ thinking visible to see where further inquiry & instruction should focus – “embedded assessment”.

ES Report:
Virtually no visitor could identify Earth when shown images like these...

Magnetic Cloud Event
October 18-20, 1995
Some Common Misconceptions about the Sun

BASED on EVERYDAY EXPERIENCE

- Earth’s seasons are caused by proximity to the Sun
- The Sun burns like fire
- The Sun is constant and unchanging
- The Sun moves to make it rise and set
- The Sun and Moon are the same size
- A child is asked: “What is more important, the Sun or the Moon?”

GENERATED BY US via METAPHOR or MODEL

- The “solar wind” is “wind on the Sun” or “wind on Earth caused by the Sun”
Science Communication Efforts in Space Weather: Benefits and Challenges of the “Weather” Analogy

Cherilynn Morrow
James Harold
Paul Dusenbery

Space Science Institute
www.spacescience.org

AMS Space Weather Symposium
San Diego, CA
11 January 2005

Hi Greg,

As far as I know, I was the first to use the phrase "Space Weather" to describe what we (AFGL) do. Back, sometime in the mid-1980s, I was asked to give a talk at a meeting in Kyoto on M-I coupling....My assigned topic was "Why the Air Force Interested in Space Research". At the time spacecraft charging was a local hot item and we had been looking at the various circumstances in which it occurred....I pitched my talk around developing an ability to identify storms on-the-way and give AF operators some warning. This struck me as analogous to what meteorologists do, hence "space weather."

Two critical things then happened:

(1) George Siscoe was in the audience. The phrase really grabbed him. "This is what we really do!" Incidentally, during his graduate student years, George had been in the Meteorology Dept at MIT. It was not uncommon for meteorologists to take space and plasma physics courses in the 1960s. George is the one who really deserves credit for publicizing the phrase as a unifying concept for geospace research and sold it as such to George Withbroe and Emie Hildner.

(2) Air Force Weather Service became interested in predicting the operational environments of various space systems...

Bill

NOTE: terms like magnetic storm and solar wind had already been in use
The Space Weather Center

A 700 sq. ft. traveling exhibit developed in collaboration between the Space Science Institute of Boulder, CO and several Sun-Earth Connection missions based at NASA/GSFC.
Reflections on Misconceptions

Terms like “space weather”, “solar wind”, and “solar storm” naturally and intentionally generate associations to the more familiar terrestrial weather: these associations are both a help and a hindrance to effectively communicating a scientific understanding.
Reflections on Misconceptions

- We have evidence from education research and evaluation efforts associated with the development and dissemination of traveling exhibits related to Sun-Earth connections, that in the minds of non-specialists, the association between terrestrial weather and space weather can conjure a variety of reasonable but wrong ideas (i.e. introduce misconceptions).
## Visitor Pre-Entry Responses

**SWC Report by Judy Koke**

<table>
<thead>
<tr>
<th>TERM</th>
<th>Related to Space Weather</th>
<th>Not related to Space Weather</th>
<th>Do not know</th>
</tr>
</thead>
<tbody>
<tr>
<td>weather satellites (A)</td>
<td>13 (59%)</td>
<td>8 (36%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>sunspots (B)</td>
<td>19 (86%)</td>
<td>2 (9%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Andromeda Galaxy</td>
<td>15 (34%)</td>
<td>10 (23%)</td>
<td>19 (43%)</td>
</tr>
<tr>
<td>Changing mag fields</td>
<td>37 (84%)</td>
<td>1 (2%)</td>
<td>6 (14%)</td>
</tr>
<tr>
<td>Aurora Borealis</td>
<td>19 (43%)</td>
<td>14 (32%)</td>
<td>11 (25%)</td>
</tr>
<tr>
<td>plasma</td>
<td>14 (32%)</td>
<td>15 (34%)</td>
<td>15 (34%)</td>
</tr>
<tr>
<td>coronal mass ejection</td>
<td>19 (43%)</td>
<td>8 (18%)</td>
<td>17 (39%)</td>
</tr>
<tr>
<td>power outages (A)</td>
<td>9 (43%)</td>
<td>7 (33%)</td>
<td>5 (24%)</td>
</tr>
<tr>
<td>clouds (B)</td>
<td>14 (64%)</td>
<td>5 (23%)</td>
<td>3 (14%)</td>
</tr>
<tr>
<td>El Nino</td>
<td>24 (54%)</td>
<td>15 (34%)</td>
<td>5 (11%)</td>
</tr>
<tr>
<td>thunderstorms</td>
<td>24 (54%)</td>
<td>14 (34%)</td>
<td>5 (11%)</td>
</tr>
<tr>
<td>sunspot cycle (A)</td>
<td>18 (82%)</td>
<td>1 (5%)</td>
<td>3 (14%)</td>
</tr>
<tr>
<td>solar wind (B)</td>
<td>22 (100%)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Comments on Misconceptions

- There is a natural tendency to define a new and unfamiliar term like “space weather” or “solar wind” by using components of the term that may be familiar in another context. So anything related to space and/or weather can be construed as being related to “space weather”.

- For example, in the SWC study a significant number of visitors answered that Andromeda Galaxy and Earth weather phenomena were each related to space weather. People had prior associations with these terms as either related to space or to weather on Earth.

- As another example, the ES Study reported visitor ideas about sunspots such as: “spots where the Sun hits the Earth” or “where the Sun hits you and burns you” or “areas of intense heat.”

- “Space Weather may be a topic about which explicit discussion of erroneous assumptions actually may help teach the major points. It might be effective to face misconceptions head on and explain that clouds and thunderstorms are not related to space weather (e.g. signage that says: Guess what is NOT related to Space Weather?)”

- Quote from the SWC Report

January 2005

Morrow – AMS Space Weather Symposium
Reflections on Misconceptions

- Modern research on how people learn tells us that misconceptions rooted in everyday experience are very difficult to change and must be confronted directly to have a chance of resolving them.

- Use of the “weather” metaphor in communicating about “space weather” can be powerful, but only if the distinctions between terrestrial weather and space weather are addressed very directly and immediately.

15 June 2010
C. A. Morrow
cmorrow@gsu.edu
Reflections on Misconceptions

- Scientists, educators, and journalists who care about effective science communication with a broader audience should be guided by the results of basic educational research on misconceptions and how people learn.
Take-Home Messages

- [Learners/audiences] are not blank slates, they come to a learning situation with their own preconceived ideas based on prior experiences.

- Misconceptions, particularly those rooted in everyday experience, are tenacious, and must be directly confronted to have a chance of giving way. This is tantamount to a personal “paradigm shift”.

- Need to focus science [instruction/communication] on [learner’s/audience member’s] ideas and meet them where they really are instead of where we think they should be.

- To be a good science communicator in any mode, it is vital to be keenly aware of common misunderstandings and effective means for addressing them. [NOTE: This is especially important for communication modes where there is not time to probe prior knowledge or to measure the impact of your communication effort.]

- It is also important to realize that unmindful use of metaphors and models can be a source of new misunderstandings.
Your Experience with Science Communication
23 respondents from AGCI Session 12-17 June 2010

- Public Talks (16)
- Newspaper Interviews (16)
- Classroom Visits (13)
- Radio Interviews (11)
- Upper division or grad course (11)
- Presenter in Teacher workshop (8)
- PI or Co-I on education-focused grant (8)
- Mentor for undergrad research project (9)
- Author or co-author of a popular article (8)
- TV interview (7)
- Instructor for graduate-level summer school (7)
- Instructor – introductory undergrad science (6)
Variety of EPO Roles for Scientists

• Presentations in a classroom or a public setting are not the only way to contribute to education and public outreach.

• There are many other roles scientists can play in education and public outreach that are suited to a diversity of talents and interests.

From “The Diversity of Roles for Scientists in K-14 Education & Public Outreach” by Cheri Morrow camorrow@colorado.edu
Types of Scientists’ Support for Science Communication

• Advocating for positive change
• Providing educational access to people, data, facilities
• Serving as content advisor/reviewer
• Mentoring/advising/partnering
• Public speaking/presenting/teaching
• Developing Curriculum or courses
• Writing popular articles or books
• Providing interviews & participating in press conferences

Adapted from “The Diversity of Roles for Scientists in K-14 Education & Public Outreach” by Cheri Morrow camorrow@colorado.edu
Phil Scherrer

Stanford University

Research Professor of Physics:
- PI for MDI on SOHO spacecraft
- PI for Magnetic Imager on SDO
- Director of Wilcox Observatory

~ 5 % time devoted to EPO:
- 1 public lecture per year
- 1 time per month with 4H club
- Encouraging staff participation

QUOTE FROM HIS PROFILE:
“As the PI of a major project, take EPO not simply as a duty, but embrace it as a key part of your activities. With a larger project you actually have an opportunity to make a big impact.”

Adapted from Profiles of Scientists in EPO. This one by Preston Dyches and Cheri Morrow. See http://ssibroker.colorado.edu/broker/PROFILES/htm
Sources of Misunderstanding

- **Phenomenological Primitives** – part of your intuitive formation as a human being experiencing everyday life that goes insufficiently challenged by science instruction.

- **Well meaning Science Instruction & Science Communication** – unwitting introduction of misconceptions based on use of metaphors, models with insufficient vigilance.

- **Mis-information campaigns** – deliberate strategies intended to plant scientifically inaccurate ideas in the public mind.

- ALL of these call for a more scholarly approach to science communication on the part of scientists, science educators, and other science communicators based in research about How People Learn.
Attributes of Scholarly Science Instruction and Science Communication

- Misconception awareness and anticipation
- Using interactive engagement techniques, ideally within a learning cycle structure (e.g. OPERA), that invite learners/listeners to think & reason for themselves;
- Being vigilant about jargon, metaphors, and models that can introduce misunderstanding;
- Relating stories about scientific investigations that make the nature of scientific inquiry explicit;
- Borrowing effective techniques from fellow communicators, preferably with attribution.

15 June 2010
C. A. Morrow cmorrow@gsu.edu
Navigating Common Misunderstandings

Examples of what many survey respondents thought was important to understand about the Sun Earth relationship:

- 99.9% of Earth’s energy input is from the Sun
- The Sun is the main source of energy for Earth’s environment
- The visible light from the Sun is the main source of energy for the Earth.
- The Sun causes weather due to differential heating of tropics vs. high latitudes.
- The Sun and Earth interact to give temperature variations.
- Reason for Seasons

Examples of common misunderstandings cited by respondents:

- The Sun is constant and unchanging.
- Failure to distinguish between weather and climate.
- The Sun causes climate change and changes in the weather
- The misunderstanding between long-term climate change and weather. For example, wondering why 0.1K change in global temperature (due to 11-year solar cycle variations) matters when temperature can change by 30° in a day.
- The idea that natural solar variations can account for 100% (rather than much less than 10%) of net observed temperature increase over the past century.

15 June 2010 C. A. Morrow cmorrow@gsu.edu
What is difficult to explain

Mechanisms associated with solar variability (e.g. the 11-year solar cycle) that physically connect solar output variations with Earth’s climate.

That solar variations on decadal time scales have a significant but not a dominant effect on climate.

The relative importance of solar changes on our atmosphere versus changes caused by human activities. This requires appreciating the relative “sizes” of effects, not just the concepts.

Evidence is strong that Sun cannot explain current climate change but public hangs onto misconceptions.

WHERE DO SUCH MISCONCEPTIONS COME FROM?
DO WE UNWITTINGLY RE-ENFORCE SOME OF THEM?

15 June 2010

C. A. Morrow
cmorrow@gsu.edu
What is difficult to explain

DO WE UNWITTINGLY RE-ENFORCE MISUNDERSTANDING?

When we do not take the time to bolster conceptual frameworks that provide the:

- basic scale and structure of the Sun-Earth system.
- important distinctions between weather, climate, climate change
- variety of temporal, spatial, scales for variability, and the meaning of a global average vs. a local measurement

And then we make (or our audiences have heard previously) the common claims about how important the Sun is to weather, climate, and temperature variations on Earth.

Do we then unwittingly re-enforce the misunderstanding that the Sun is the primary cause of climate change?
Learning Cycle - OPERA

- **O** for Opening – Private Universe & Discussion of Learning Theory & How People Learn
- **P** for Prior knowledge – Pre-session Survey about Your Experience with Common Misunderstandings
- **E** for Experience – Thinking about the Animation
- **R** for Reflection – Considering other sources of misunderstandings that we generate. Summarizing advantages & disadvantages of communication techniques. Need for vigilance with models & metaphors.
- **A** for Assessment and Application – consider applying to the case of communicating about the relationship of solar variability and climate change.

15 June 2010  C. A. Morrow  cmorrow@gsu.edu