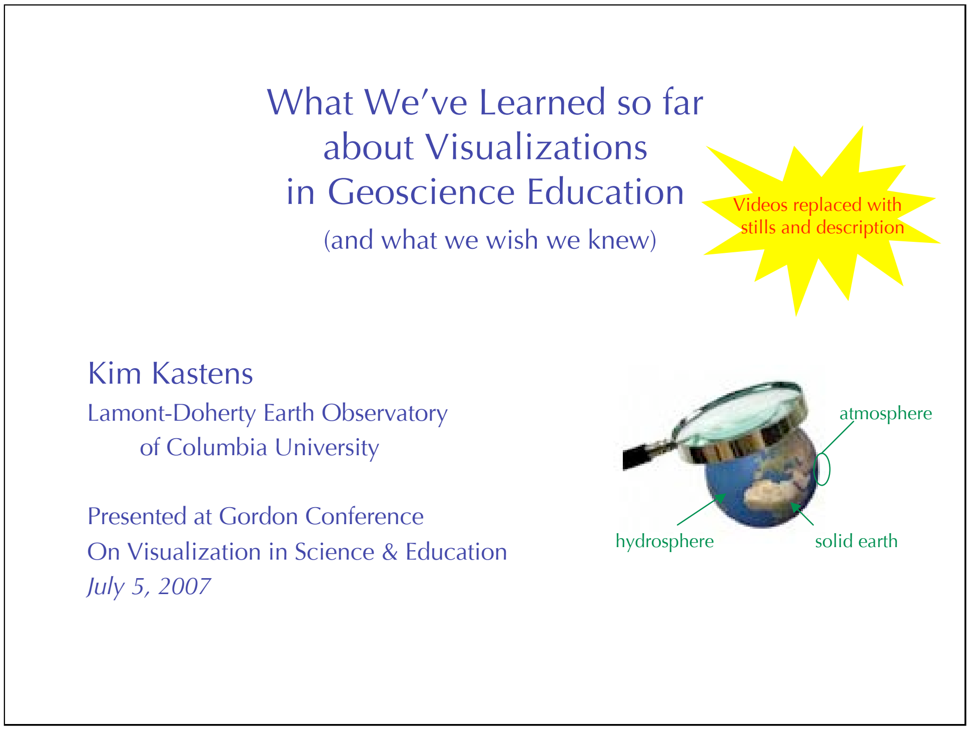


What We've Learned so far about Visualizations in Geoscience Education

(and what we wish we knew)

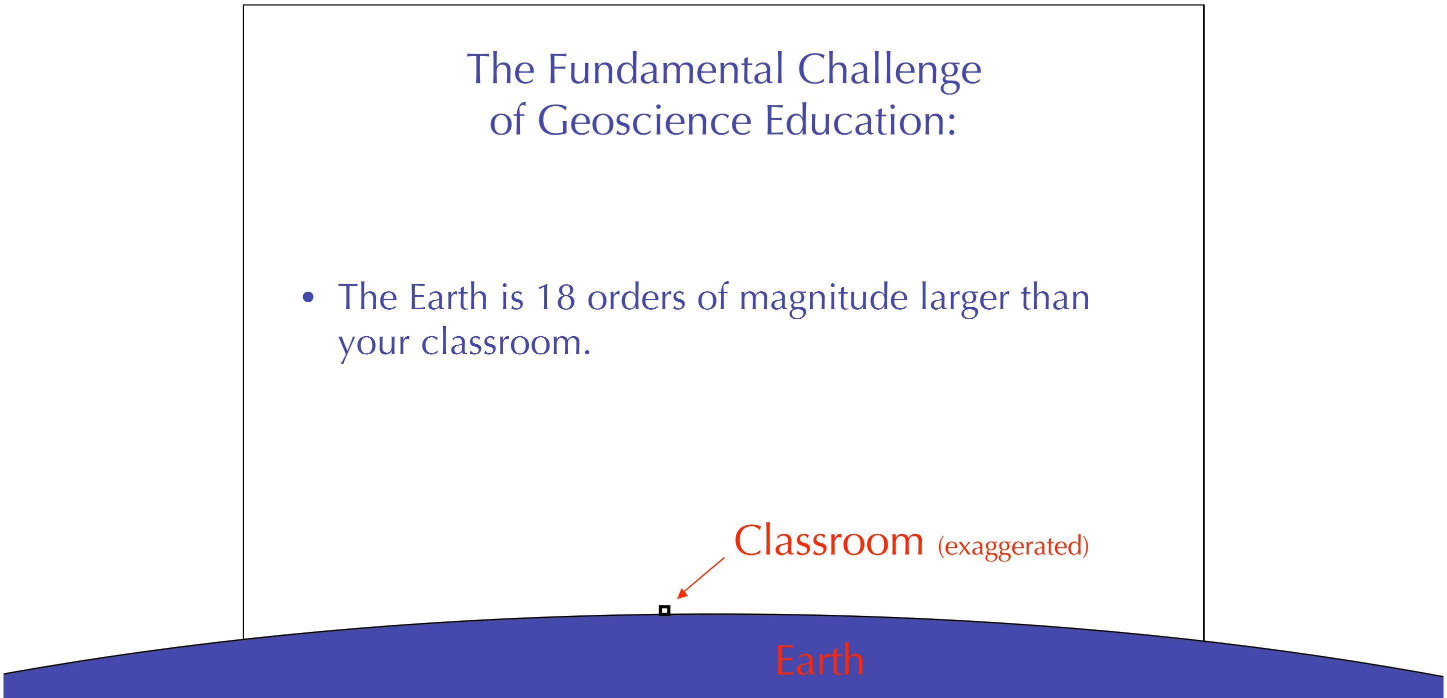
Videos replaced with stills and description

Kim Kastens
Lamont-Doherty Earth Observatory
of Columbia University

Presented at Gordon Conference
On Visualization in Science & Education
July 5, 2007

Good morning. I'm hear to kick off the first of three talks on what we've learned about visualization in geoscience education. Geosciences these days includes the study of the solid earth, atmosphere, and hydrosphere, plus their interactions with each other, and some aspects of their interactions with human beings and with the biosphere more broadly.

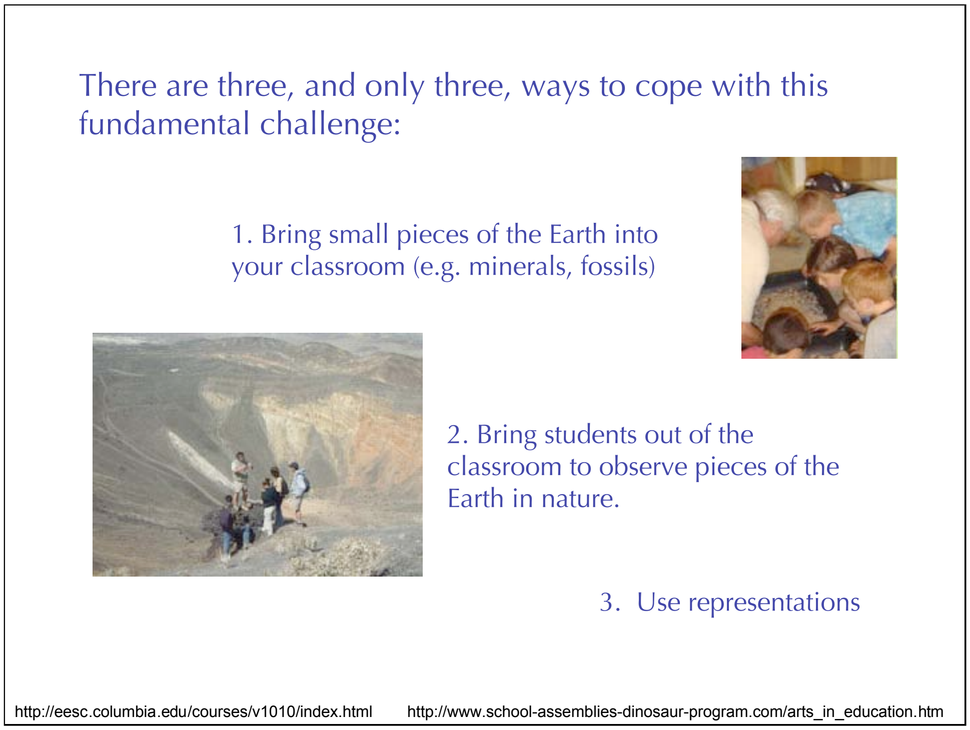
NOTE: This pdf version of the powerpoint, prepared for distribution to colleagues, has been edited to omit references to ideas presented by other Gordon Conference speakers, in accordance with Gordon Conference policy. Also, the talk as I gave it had 3 video snippets, which have been replaced by stills and descriptions of the videos, to get a file small enough to distribute.



The Fundamental Challenge of Geoscience Education:

- The Earth is 18 orders of magnitude larger than your classroom.

The fundamental challenge of geosciences is in some ways the opposite of chemistry. Our fundamental challenge is that the Earth is 18 orders of magnitude larger than our classrooms, and even a small subsystem, such as a watershed or estuary is still several orders of magnitude larger than our classroom.



There are three, and only three, ways to cope with this fundamental challenge:

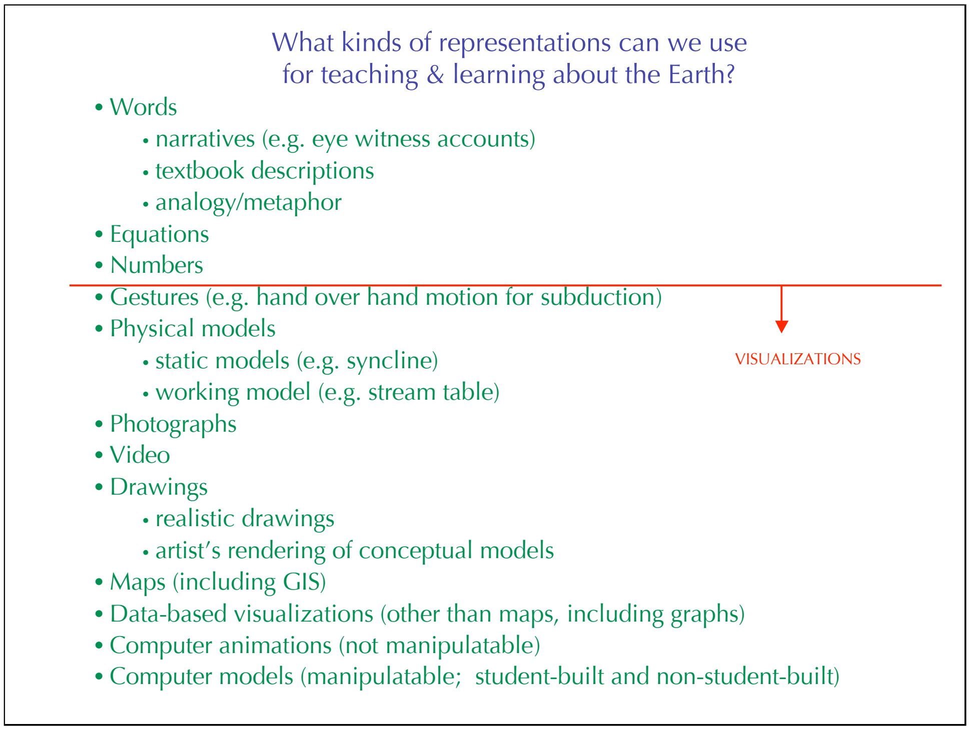
1. Bring small pieces of the Earth into your classroom (e.g. minerals, fossils)

2. Bring students out of the classroom to observe pieces of the Earth in nature.

3. Use representations

http://eesc.columbia.edu/courses/v1010/index.html http://www.school-assemblies-dinosaur-program.com/arts_in_education.htm

There are three, exactly three, ways to cope with this challenge. First: bring small pieces of the Earth into your classroom or lab for examinations, including fossils and minerals and rocks, and also air, water and rock samples for examination and analysis. [click] Second, bring students out of the classroom into the field to gain a first-hand sense of the scale and complexity of the actual Earth. [click) Third, use representations. Those are the only options; every teaching and learning event in earth science education builds on these strategies. A complete geoscience education uses all three. All have affordances and all have limitations. The field option is expensive and logistically challenging. Bringing in objects of nature only works for certain types of inquiries. And thus we rely heavily on option 3, using representations.

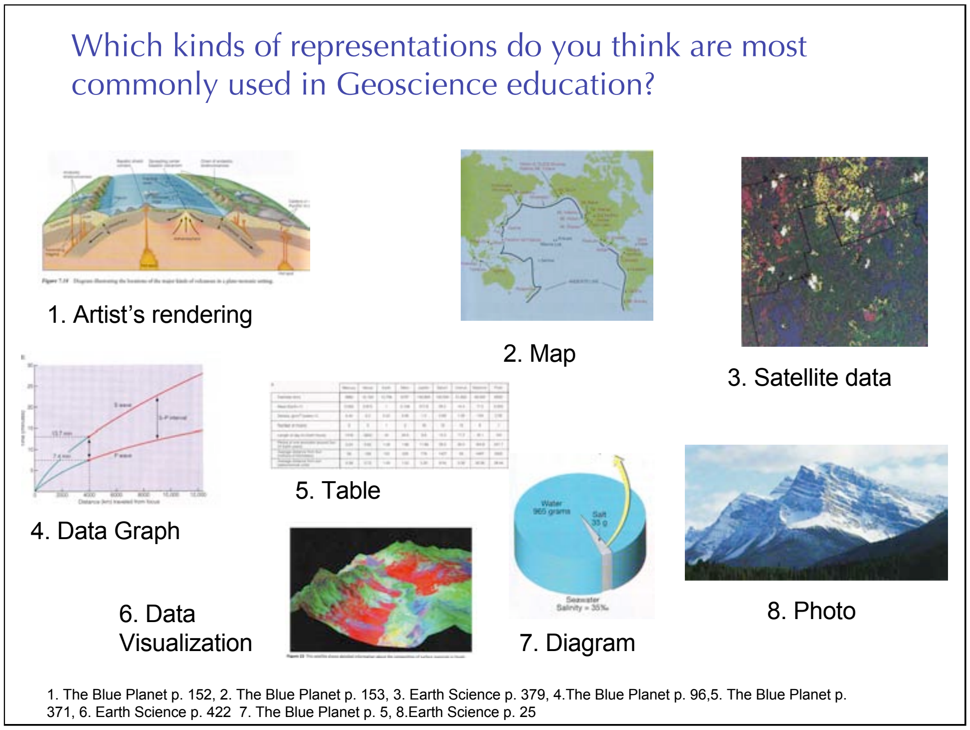


What kinds of representations can we use for teaching & learning about the Earth?

- Words
  - narratives (e.g. eye witness accounts)
  - textbook descriptions
  - analogy/metaphor
- Equations
- Numbers
- Gestures (e.g. hand over hand motion for subduction)
- Physical models
  - static models (e.g. syncline)
  - working model (e.g. stream table)
- Photographs
- Video
- Drawings
  - realistic drawings
  - artist's rendering of conceptual models
- Maps (including GIS)
- Data-based visualizations (other than maps, including graphs)
- Computer animations (not manipulatable)
- Computer models (manipulatable; student-built and non-student-built)

VISUALIZATIONS

Here is a taxonomy of some of the many kinds of representations used in teaching and learning about the Earth. Those below the red line could be considered as "visualizations."



Which kinds of representations do you think are most commonly used in Geoscience education?

1. Artist's rendering

2. Map

3. Satellite data

4. Data Graph

5. Table

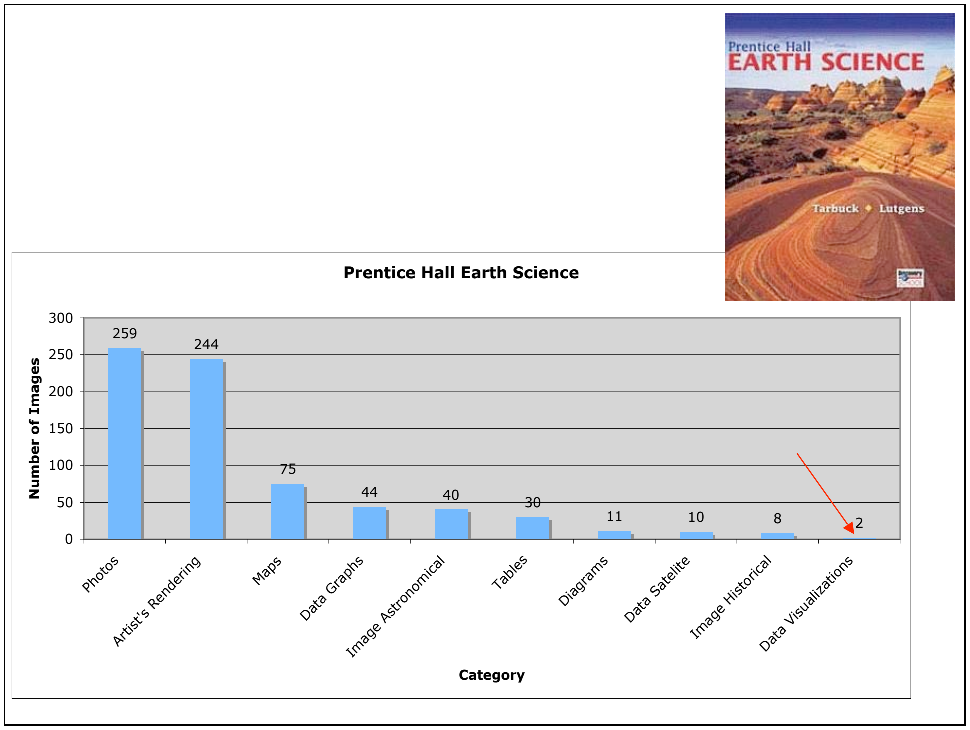
6. Data Visualization

7. Diagram

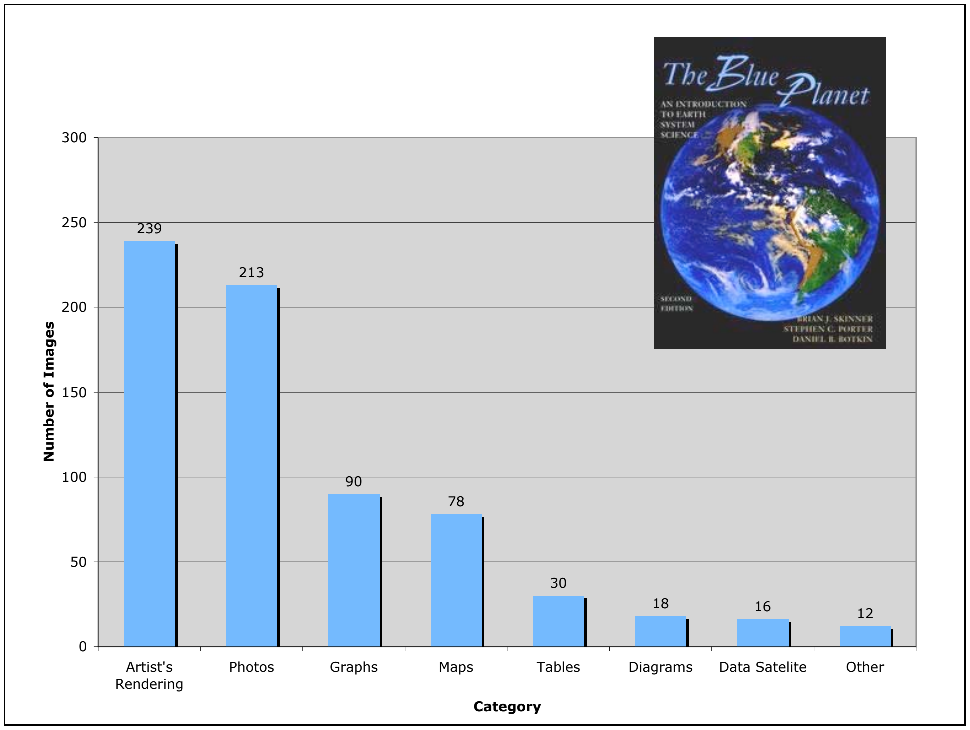
8. Photo

1. The Blue Planet p. 152, 2. The Blue Planet p. 153, 3. Earth Science p. 379, 4.The Blue Planet p. 96,5. The Blue Planet p. 371, 6. Earth Science p. 422 7. The Blue Planet p. 5, 8.Earth Science p. 25

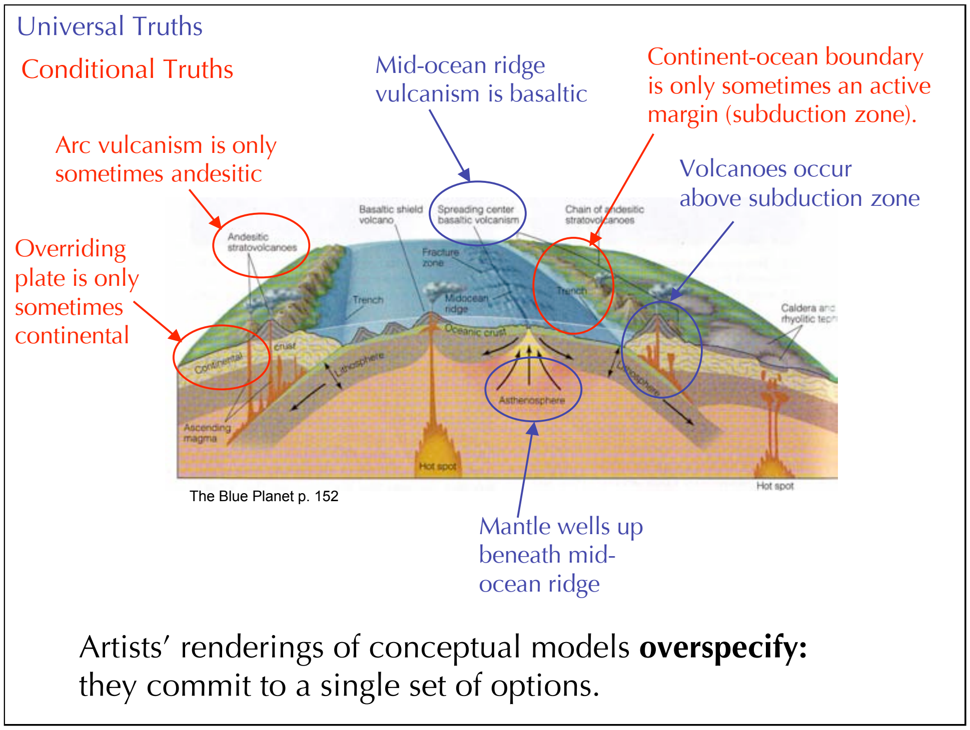
So we have access to a lot of kinds of representations. Which do you think are most commonly used in actual educational settings with actual teachers and actual students? Make a mental note of the two kinds of representations that you think would be most used in geoscience education. I can't actually answer this question for education in general, but as a first cut…



… we analysed the representations in two widely used Earth Science textbooks. Students encounter hundreds of illustrations in such textbooks. In one high school textbook, shown here, the most commonly used representations were photos and artist’s renderings, followed by maps. Data visualizations, of the sort we have been talking about here, barely register.



Similarly, in a college textbook, artist's renderings and photos dominate. So we'd better take closer, more critical look at these artist's renderings, which so dominate our students' exposure to earth science.



Universal Truths

Conditional Truths

Mid-ocean ridge vulcanism is basaltic

Continent-ocean boundary is only sometimes an active margin (subduction zone).

Arc vulcanism is only sometimes andesitic

Volcanoes occur above subduction zone

Overriding plate is only sometimes continental

The Blue Planet p. 152

Mantle wells up beneath mid-ocean ridge

Artists' renderings of conceptual models **overspecify:** they commit to a single set of options.

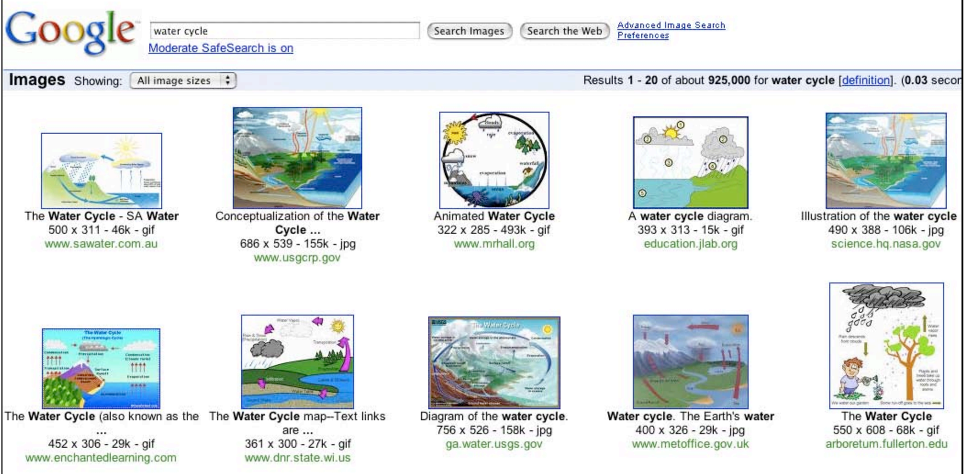
First of all, these artist's rendition compress a huge amount of information into an efficient package. As a marine geologist, I can tell you that decades of ship time and years of oceanographer-time were required to collect and analyze the bathymetric data that underlies this simple sketch of the seafloor fabric. This diagram is powerful as a communication tool.

Click one: But if we look more closely, we see that diagram confounds two kinds of information. Some things in this diagram are approximately always true, such as [read blue items].

Click two: But other things in this diagram are only sometimes true, or conditionally true [read red items]. The nature of this kind of artist's rendering is that you have to fill up all the spaces, you have to commit to one set of of options. If you want to show an overriding plate and it can be either continental or oceanic, you can't show both options in the same place at the same time.

Click three: Or to summarize this point, artist's renderings of conceptual models overspecify: they commit to a single set of options for a system which has, in fact, many permutations.

Search term: “Water Cycle”



water cycle

Results **1** - **20** of about **925,000** for **water cycle** [definition]. (**0.03** secor

The **Water Cycle** - SA **Water**
500 x 311 - 46k - gif
www.sawater.com.au

Conceptualization of the **Water Cycle ...**
686 x 539 - 155k - jpg
www.usgcrp.gov

Animated **Water Cycle**
322 x 285 - 493k - gif
www.mrhall.org

A **water cycle** diagram.
393 x 313 - 15k - gif
education.jlab.org

Illustration of the **water cycle**
490 x 388 - 106k - jpg
science.hq.nasa.gov

The **Water Cycle** (also known as the ...
452 x 306 - 29k - gif
www.enchantedlearning.com

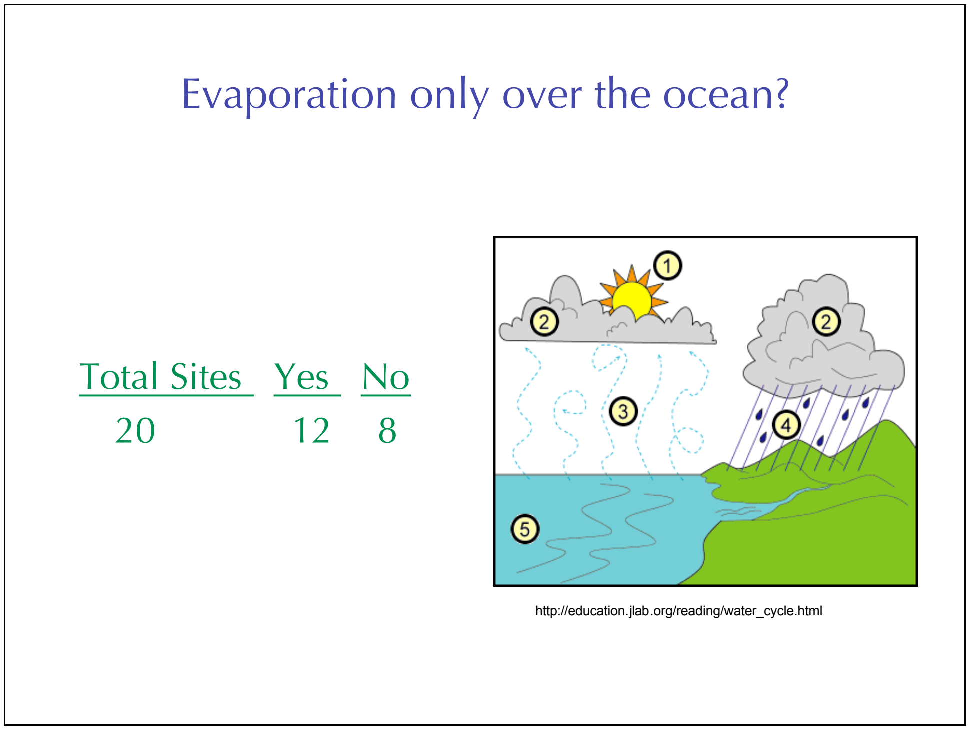
The **Water Cycle** map--Text links are ...
361 x 300 - 27k - gif
www.dnr.state.wi.us

Diagram of the **water cycle**.
756 x 526 - 158k - jpg
ga.water.usgs.gov

Water cycle. The Earth's **water**
400 x 326 - 29k - jpg
www.metoffice.gov.uk

The **Water Cycle**
550 x 608 - 68k - gif
arboretum.fullerton.edu

Let’s take another example that appears again and again in earth & environmental science lessons from elementary school through college: the water cycle. Here you see examples from a variety of sources: U.S. government agencies (USGS, NASA), the UK, the South Australia water utility, an informal science education organization, an education company. Each one is a little different, and yet they are surprisingly similar, in ways that are not driven by the science.



Evaporation only over the ocean?

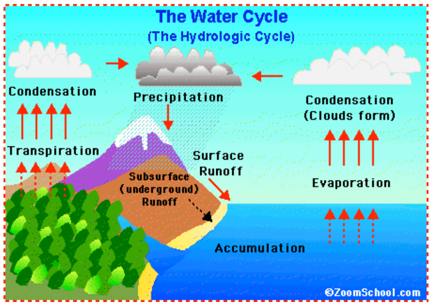
Total Sites	Yes	No
20	12	8

http://education.jlab.org/reading/water_cycle.html

If you look the top 20 “Water Cycle” images returned by Google image search for “water cycle”, leaving out duplicates and ones with actual factual errors, 12 of the 20 show evaporation only over the ocean. Obviously evaporation happens everywhere, but if you show evaporation everywhere there’s no room to show anything else.

Precipitation only on land/continents?

Total Sites	Yes	No
20	16	4

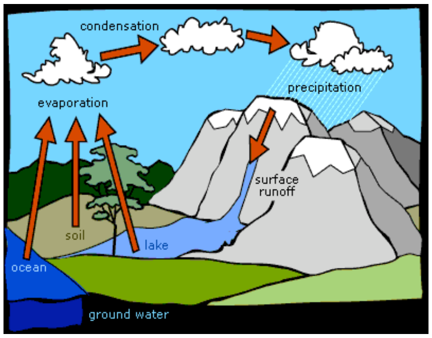


http://www.enchantedlearning.com/subjects/ocean/Watercycle.shtml

Sixteen of the twenty show precipitation only on land.

Precipitation only over the mountains?

Total Sites	Yes	No
20	11	9

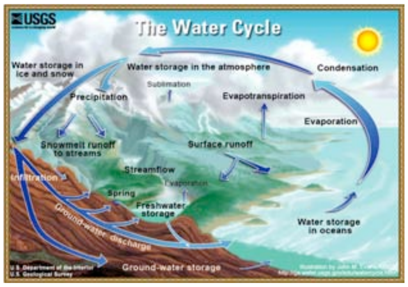


http://www.troy.k12.ny.us/faculty/dibarij/earth%20science/117.html

An of those, 11 show precipitation only over the mountains.

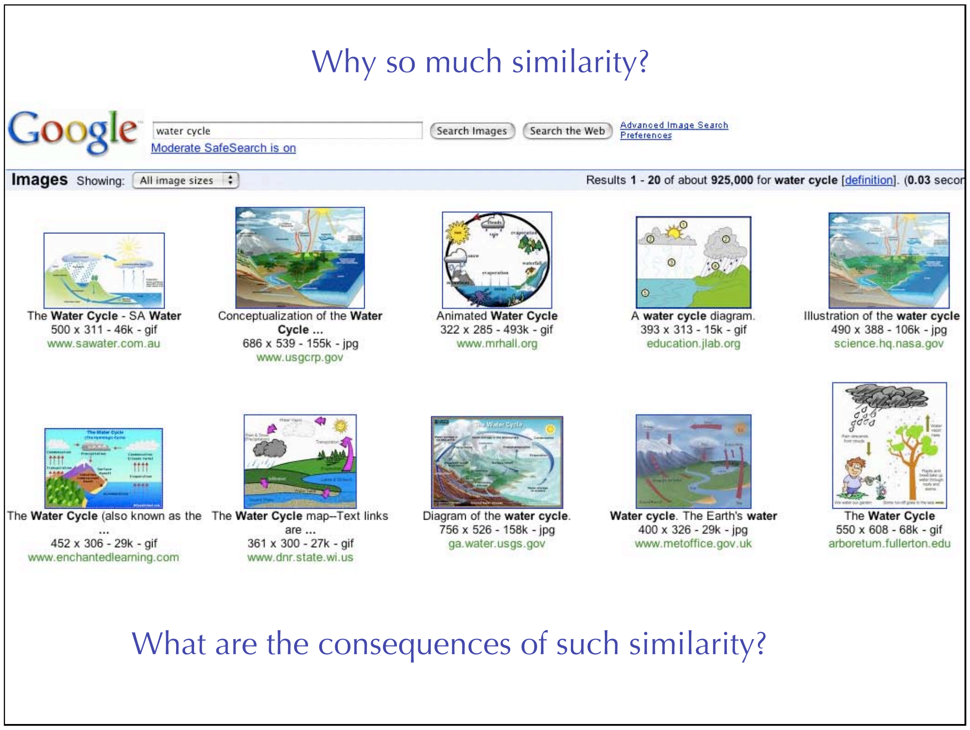
Land on the left and ocean on the right?

Total Sites	Yes	No
20	15	5



http://ga.water.usgs.gov/edu/graphics/watercyclehigh.jpg

And here’s a really strange one: 15 of the 20 images show the ocean on the right and land on the left, which gives you a counterclockwise flow of water through the water cycle.



Why so much similarity?

water cycle

Images Showing: All image sizes

Results **1** - **20** of about **925,000** for **water cycle** [definition]. (**0.03** secor

The **Water Cycle** - SA **Water**
500 x 311 - 46k - gif
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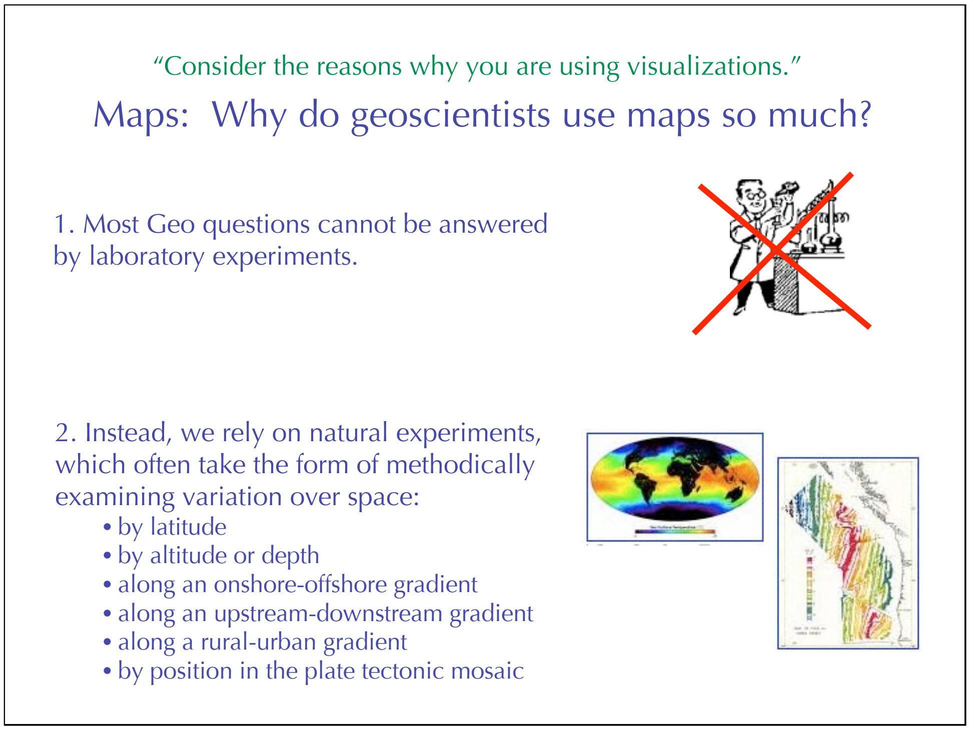
The **Water Cycle**
550 x 608 - 68k - gif
arboretum.fullerton.edu

What are the consequences of such similarity?

So it's not just that individual conceptual drawings overspecify one set of possibilities at the expense of others. Somehow the whole suite of images overspecifies the same set of possibilities: evaporation happens over the ocean and so on. Why does this happen? Is this common descent from some Ur-watercycle-diagram of decades ago? Or some kind of Richard Dawkins -like cultural transmission of the visual water cycle meme? I'd love to know.

Perhaps a more important question is "what are the consequences?" If a young person sees such a diagram in middle school, and another in Girl Scouts, and another in high school, and another in the newspaper, can we expect them to think that evaporation does indeed always (or almost always) occur over the ocean, precipitation always on land, and so on?



"Consider the reasons why you are using visualizations."

Maps: Why do geoscientists use maps so much?

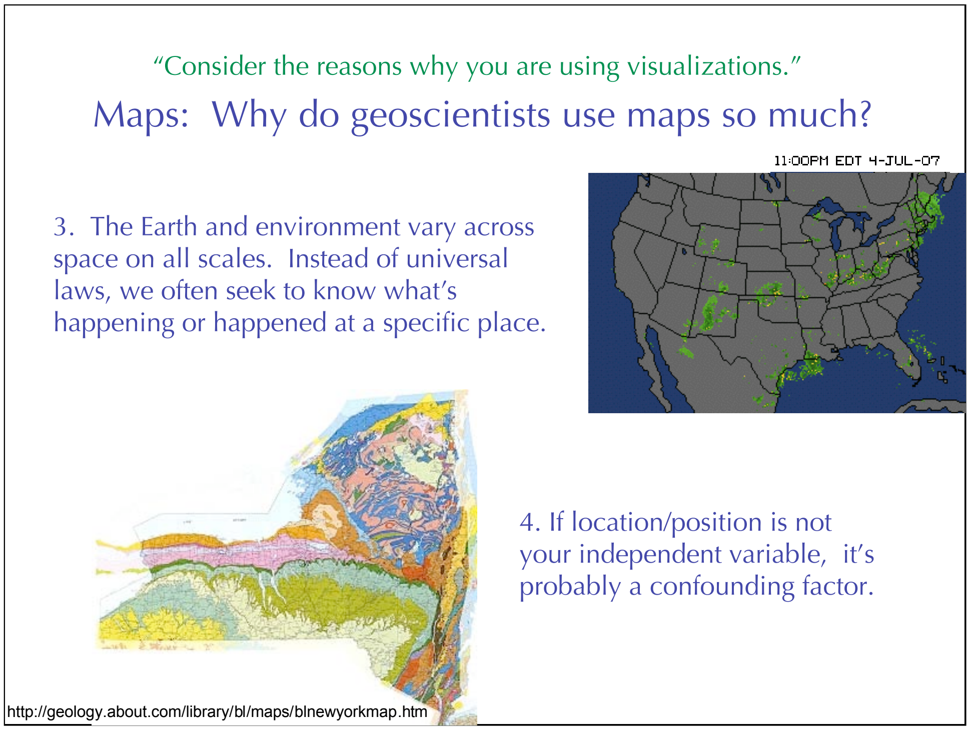
1. Most Geo questions cannot be answered by laboratory experiments.

2. Instead, we rely on natural experiments, which often take the form of methodically examining variation over space:
   - by latitude
   - by altitude or depth
   - along an onshore-offshore gradient
   - along an upstream-downstream gradient
   - along a rural-urban gradient
   - by position in the plate tectonic mosaic

A speaker told us yesterday that we should be sure to consider WHY we are using visualizations, so I thought I would introduce my next type of visualization, maps, by asking why do geoscientists use maps so much. If you come to my research institute, the Earth & Environmental research campus of Columbia University, you will find maps on the walls of the corridors of every building, the Seismologists' corridor, the oceanographers' corridor, no matter the subspeciality, we all use maps as one of our central tools for organizing and conveying both our data and our ideas.

[click] One reason is that few questions in geosciences can be answered by laboratory experiments.

[click] Instead we rely on natural experiments, which often take the form of methodically examining variation over space, perhaps by latitude as in this sea surface temperature data, or altitude, or along an onshore-offshore gradient, or a rural urban gradient, or by position relative to a plate tectonic feature such as the Juan de Fuca spreading center plate boundary in this map of seafloor magnetic anomalies.



"Consider the reasons why you are using visualizations."

Maps: Why do geoscientists use maps so much?

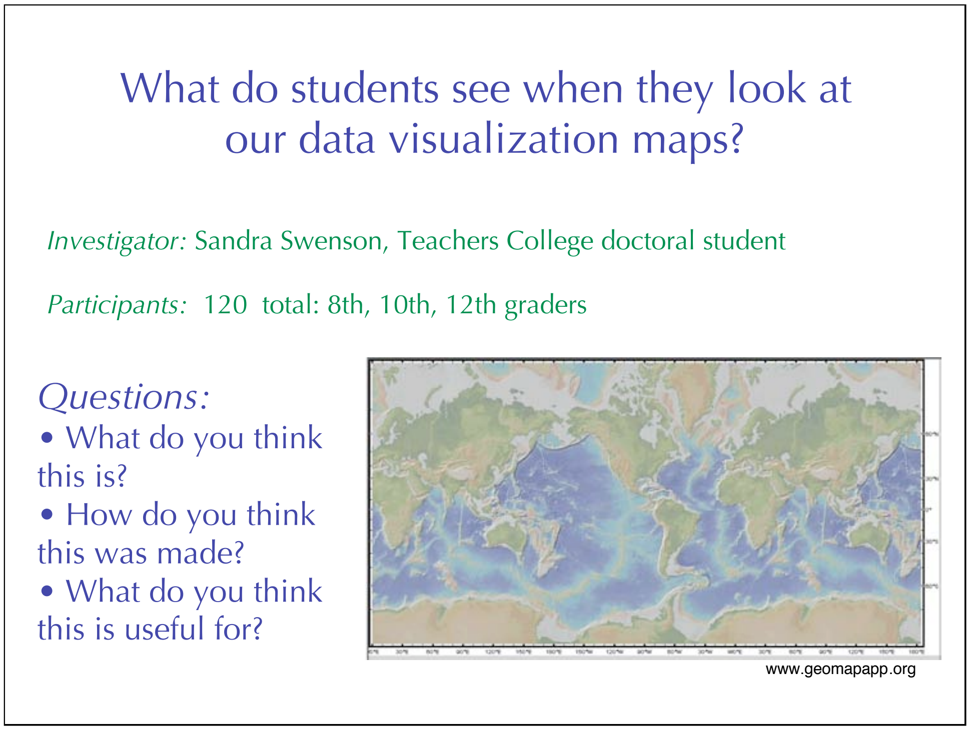
3. The Earth and environment vary across space on all scales. Instead of universal laws, we often seek to know what's happening or happened at a specific place.

4. If location/position is not your independent variable, it's probably a confounding factor.

http://geology.about.com/library/bl/maps/blnewyorkmap.htm

Another reason why we use maps so much is that the Earth and environment vary spatially, on every scale from a single handsized rock up to the scale of entire continents or oceans. Chemists and physics seek universal truths, phenomena that occur regardless of where the experiment was carried out. Earth scientists care very much about things that are not the same everywhere, and often want to know what's happening or happened or is predicted to happen at their particular spot of interest: for example, is it likely to rain in Rhode Island on July 4, 2007.

[click] And finally, because the earth is so heterogeneous, if location is not an independent variable in your study, it's likely to be a confounding factor. Have I covered enough area to average out across the spatial heterogeneity? Has my location biased my findings? So that's why geoscientists are so obsessed with maps.



What do students see when they look at our data visualization maps?

Investigator: Sandra Swenson, Teachers College doctoral student

Participants: 120 total: 8th, 10th, 12th graders

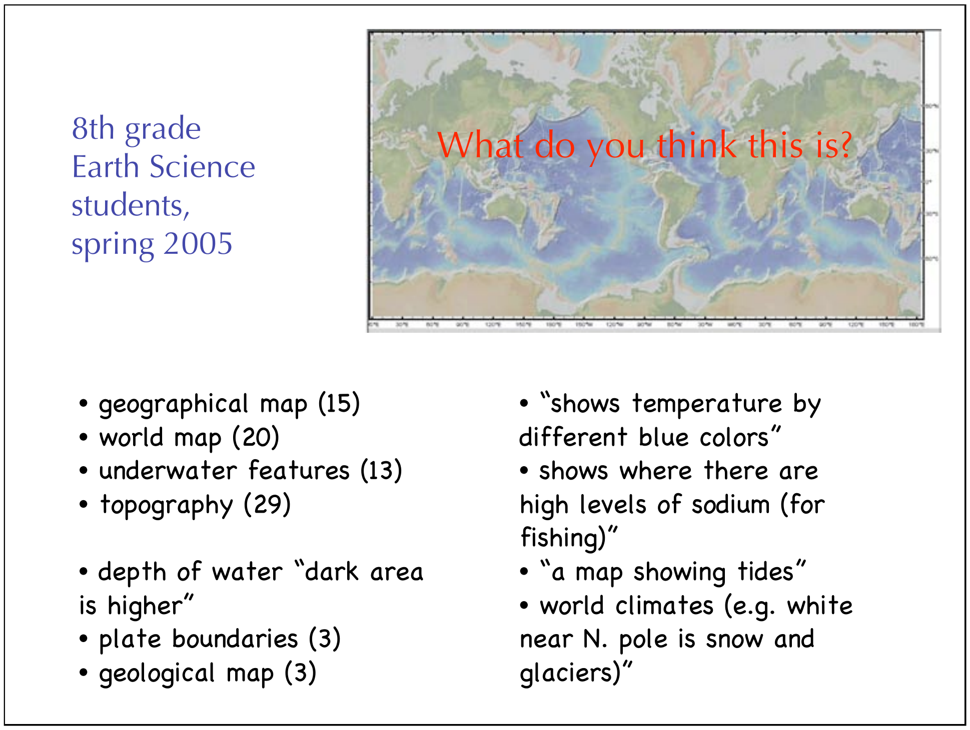
Questions:
- What do you think this is?
- How do you think this was made?
- What do you think this is useful for?

www.geomapapp.org

Now here you see an truly fundamental iconic data visualization in my field: a digital elevation model of the world's topography and bathymetry as displayed by GeoMapApp. I or my colleagues look at this, and know instantly what it is, no labels, no key necessary. We'd be inclined to plunge right in at the deep end and start blathering on about, "well here you see a bathymetric gradient from shallower at the zero age crust along the mid-Atlantic Ridge increasing symmetrically towards older crust, and that's indicative of….. Etc, etc."

But I'm coming to realize that with students we have to go way, way back from that starting point.

[click] My collaborator on the GeoMapApp project, Sandra Swenson, asked students in grades 8 through 12, three simple but profound questions about this image: [read questions]



8th grade
Earth Science
students,
spring 2005

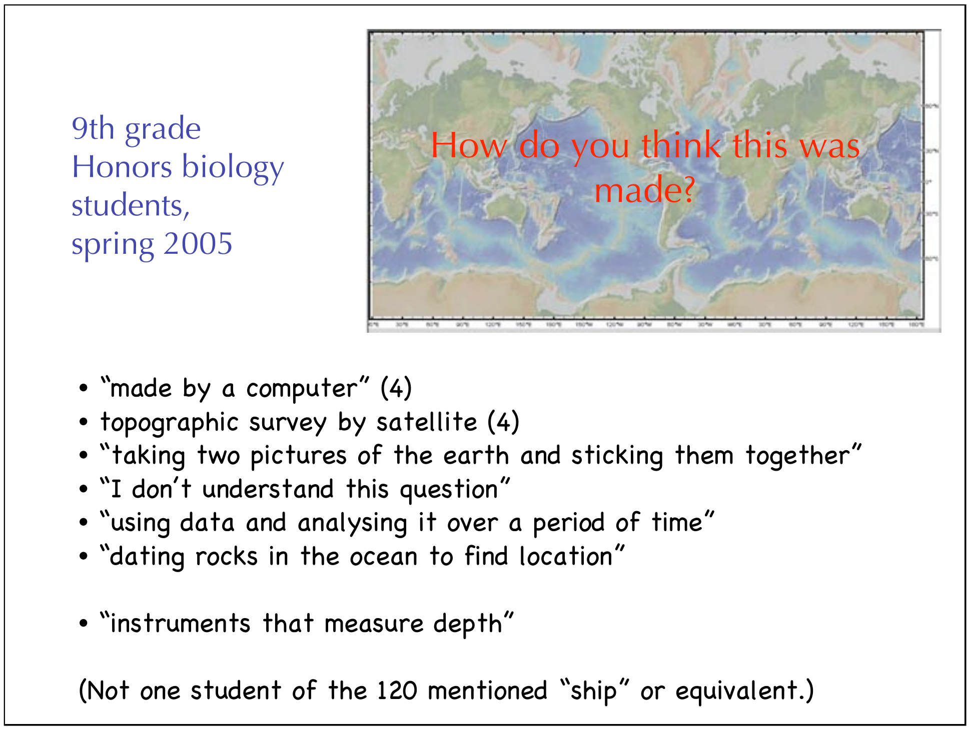
What do you think this is?

- geographical map (15)
- world map (20)
- underwater features (13)
- topography (29)

- depth of water "dark area is higher"
- plate boundaries (3)
- geological map (3)

- "shows temperature by different blue colors"
- shows where there are high levels of sodium (for fishing)"
- "a map showing tides"
- world climates (e.g. white near N. pole is snow and glaciers)"

In response to "What do you think this is?" many students had answers we would anticipate, such as "world map" or "topography." But there were answers that were so far removed from the experts answer that they make jaws drop when I show them to other marine geologists.



9th grade
Honors biology
students,
spring 2005

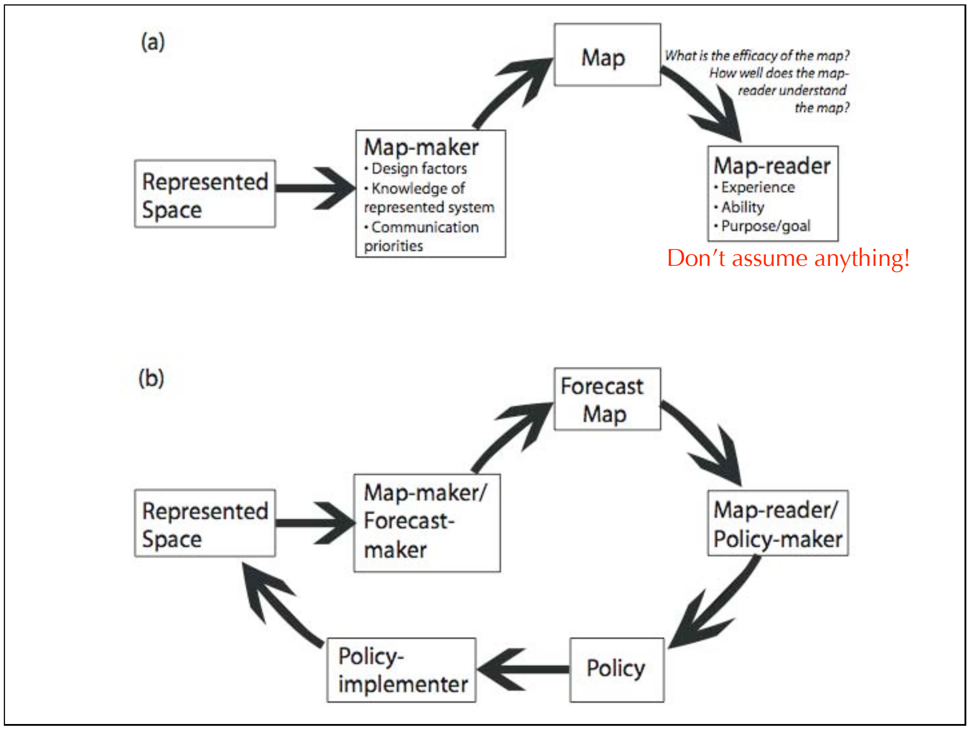
How do you think this was made?

- "made by a computer" (4)
- topographic survey by satellite (4)
- "taking two pictures of the earth and sticking them together"
- "I don't understand this question"
- "using data and analysing it over a period of time"
- "dating rocks in the ocean to find location"

- "instruments that measure depth"

(Not one student of the 120 mentioned "ship" or equivalent.)

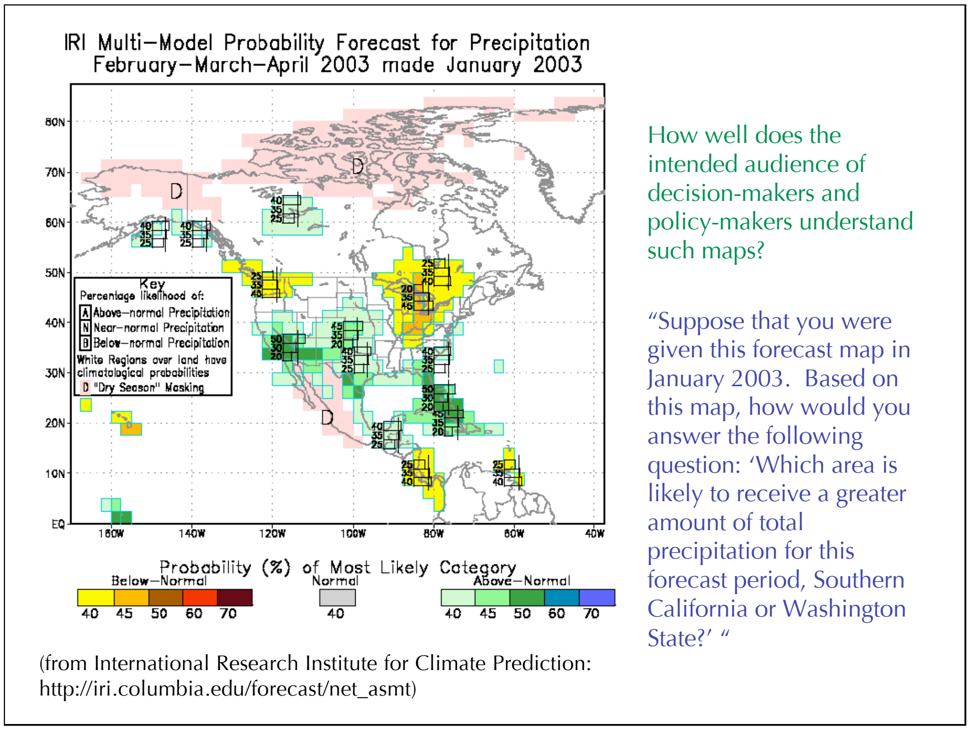
In response to "How do you think this was made?" students produced a range of answers, but not one student mentioned a ship, which is the dominate data source for the ocean part of the data set. Four mentioned "made by a computer," so I'm worried that we have students who think that data comes from computers, who don't understand that data comes from the earth.



Don't assume anything!

Earlier in the week we heard about senders and receivers of information conveyed by animations. Here is version of that idea from cartography. Out here to the left exists reality, the Earth or a portion of the Earth. The map-maker (or visualization maker) makes some decisions about what aspects of that reality to try to convey and conveys as best he or she can into a map, which then goes to the map reader. The arrows represent information flows, and at each arrow there is a loss or distortion of information. My take home lesson from the previous study is that I should not assume ANYTHING about how much information gets through to the map-reader or more generally, the visualization viewer.

[click twice] These days geosciences often deals with interactions between humanity and the earth, for example, global climate change. This means that in some cases, this information flow can become a closed loop, when the map-reader makes a decision or forms a policy that results in an action that causes a change upon the Earth. The second map study I will report looks at the potential of this kind of closed loop. The participants were masters degree students in the Environmental Policy program at Columbia's School of International and Policy Affairs, so they were training to become environmental decision-makers.

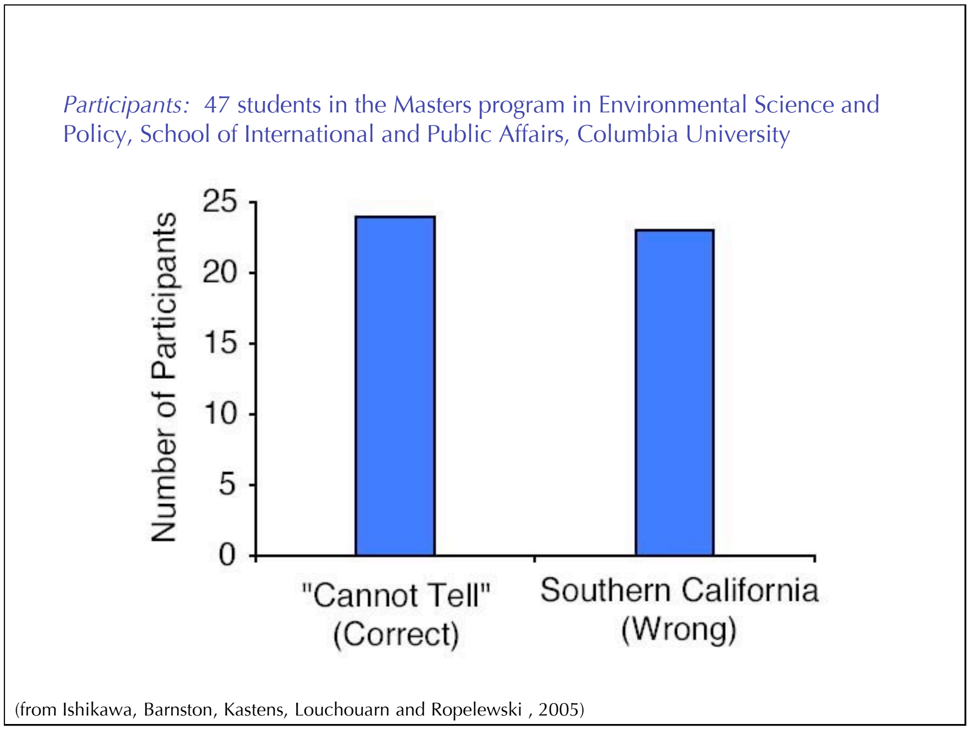


(from International Research Institute for Climate Prediction: http://iri.columbia.edu/forecast/net_asmt)

How well does the intended audience of decision-makers and policy-makers understand such maps?

"Suppose that you were given this forecast map in January 2003. Based on this map, how would you answer the following question: 'Which area is likely to receive a greater amount of total precipitation for this forecast period, Southern California or Washington State?' "

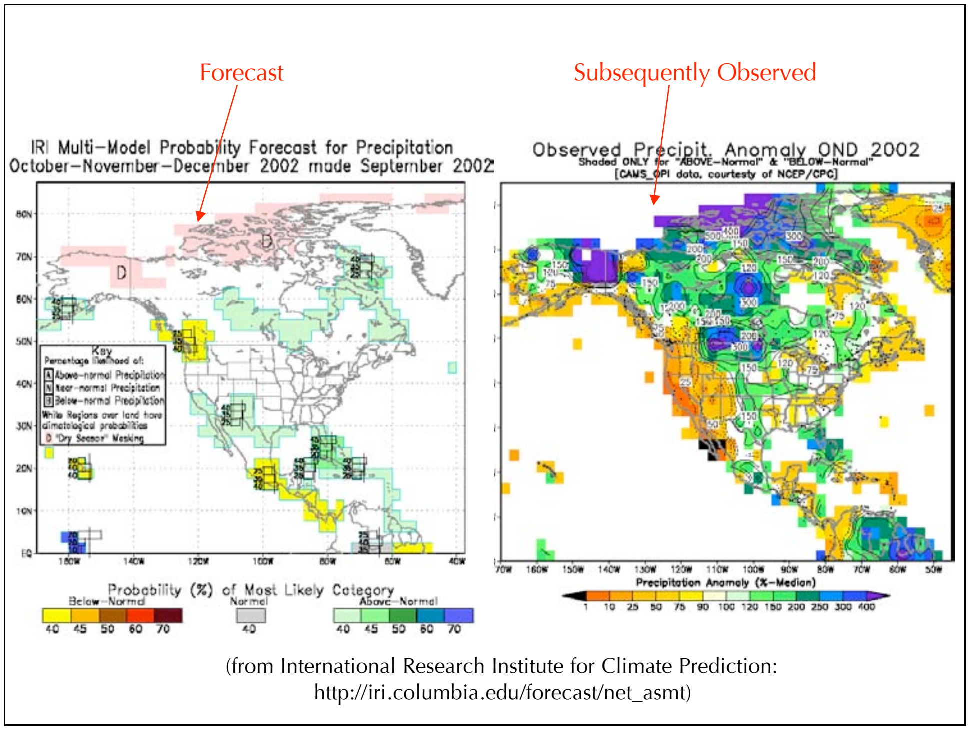
The maps we examined show forecasts of precipitation three months out into the future. The forecasts and maps are map by the International Research Institute for Climate Prediction. It is an explicit part of the mission of this institute to disseminate precipitation and temperature forecasts in a way that will be useable by, and used by, people who make decisions about things like what crops to plant, how much water to retain in reservoirs and similar societally important issues. The maps show the probability that precipitation will be above normal or below normal, with the different colors indicating the probability of the most likely category. For example, these yellow areas have 40% probability of below normal precip, defined as in the lowest quartile of precip over the historical record. One question we asked, a bit tricky, was {read question]



Participants: 47 students in the Masters program in Environmental Science and Policy, School of International and Public Affairs, Columbia University

(from Ishikawa, Barnston, Kastens, Louchouarn and Ropelewski , 2005)

Students wrote in answers to the question. Half got it wrong, writing that Southern California would get more rain. But in fact, all we know from the map is that Southern California is forecast to receive more rain than normal for Southern California and Washington State is forecast to receive less than normal for that locality. The correct answer is “Cannot tell.” I should also mention that the program is 1/3 environmental science, and we conducted our study during the hydrology unit of the science semester, so they had been actively thinking about water and water resources. It is also part of their training as policy makers to evaluate the adequacy of information for decision makers, so “cannot tell” as a correct answer was not a trick question for this population.

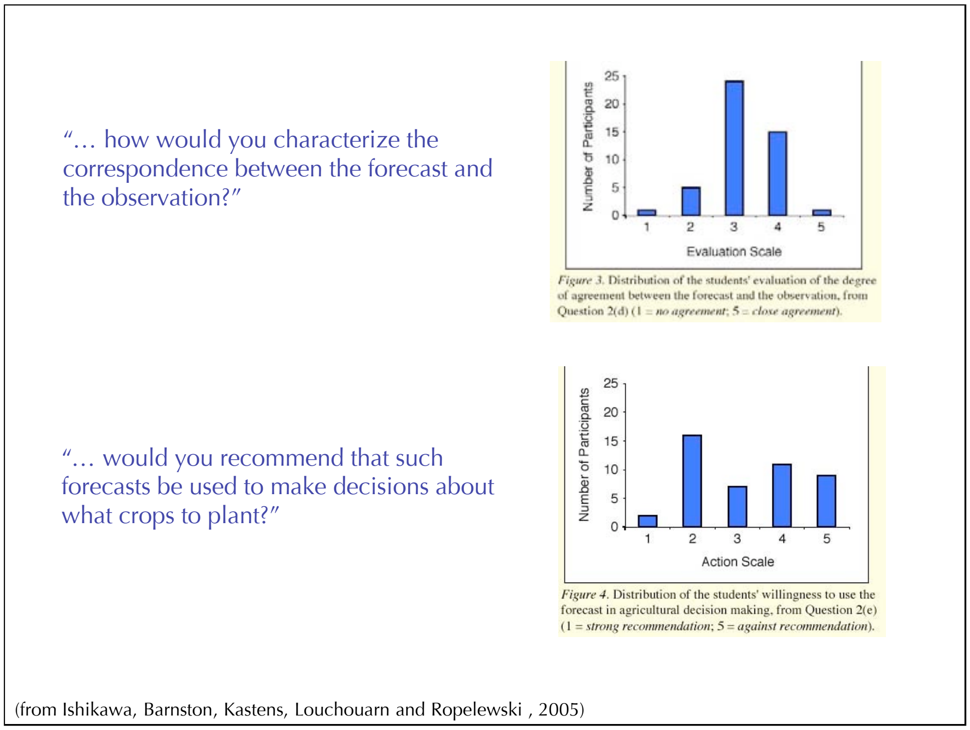


Forecast

Subsequently Observed

(from International Research Institute for Climate Prediction:
http://iri.columbia.edu/forecast/net_asmt)

Next, we gave them two maps. One showed the forecast precip for winter of 2002, as forecast the preceding September. The other showed how much precipitation actually did fall as it turned out.



"… how would you characterize the correspondence between the forecast and the observation?"

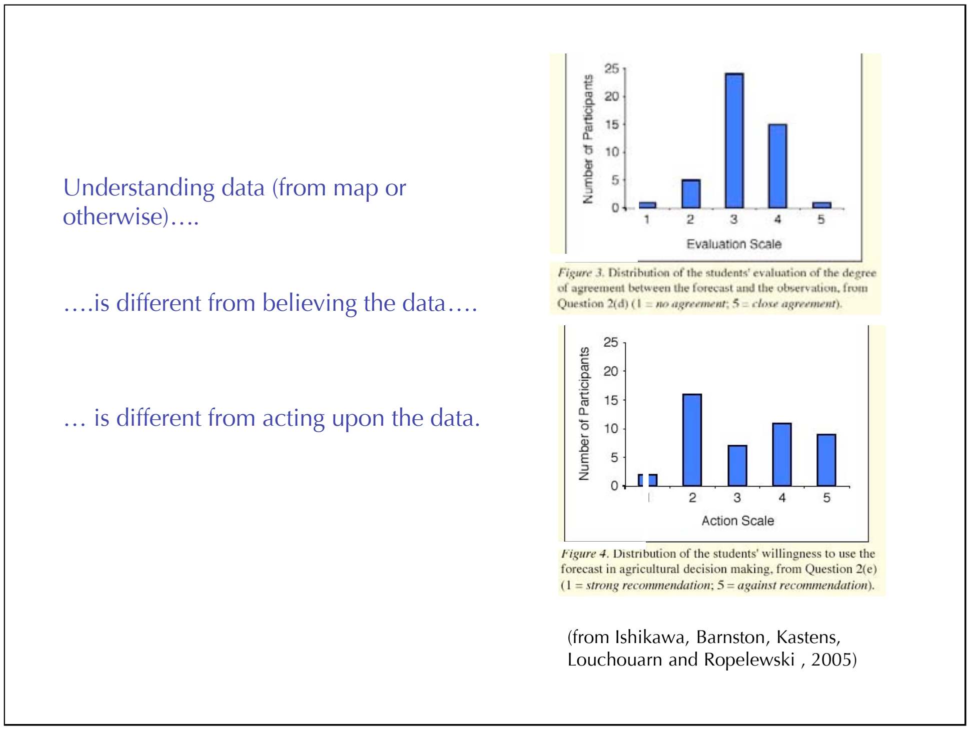
Figure 3. Distribution of the students' evaluation of the degree of agreement between the forecast and the observation, from Question 2(d) (1 = *no agreement*; 5 = *close agreement*).

"… would you recommend that such forecasts be used to make decisions about what crops to plant?"

Figure 4. Distribution of the students' willingness to use the forecast in agricultural decision making, from Question 2(e) (1 = *strong recommendation*; 5 = *against recommendation*).

(from Ishikawa, Barnston, Kastens, Louchouarn and Ropelewski , 2005)

We asked how they would characterize the correspondence between the forecast and the actual precip. They mostly fell in the middle of a five point scale. And then we asked how likely they would be to use information like that in the forecast map to make recommendations about a societally-important decision, what crops to plant. Here we found less agreement, more scatter, with very few people neutral on the topic. Individual future policy makers who found the forecasts credible, in other words in reasonable agreement with reality as it eventually played out, were not necessarily willing to commit to actually using these kinds of forecasts for an economically or societally important decision.



Understanding data (from map or otherwise)….

….is different from believing the data….

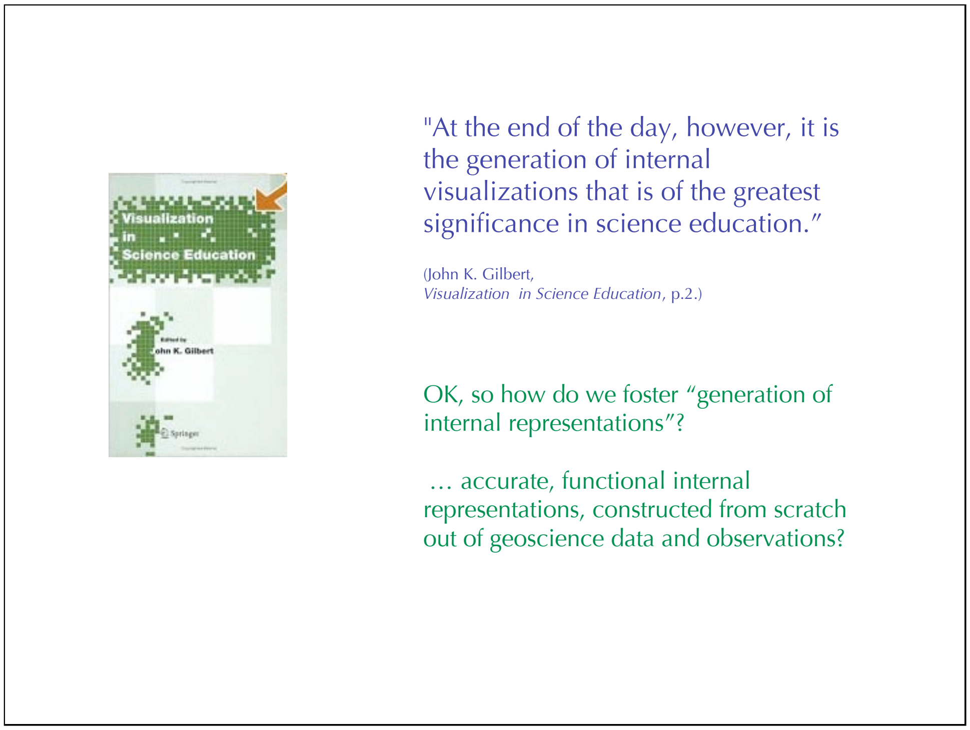
… is different from acting upon the data.

Figure 3. Distribution of the students' evaluation of the degree of agreement between the forecast and the observation, from Question 2(d) (1 = *no agreement*; 5 = *close agreement*).

Figure 4. Distribution of the students' willingness to use the forecast in agricultural decision making, from Question 2(e) (1 = *strong recommendation*; 5 = *against recommendation*).

(from Ishikawa, Barnston, Kastens, Louchouarn and Ropelewski , 2005)

So this week we’ve talked a lot about whether the student or other viewer understands the data visualization, map or otherwise. I’d like to suggest that an equally important question is does the viewer believe that the visualization is an accurate and credible depiction of a represented reality? And finally, is the viewer willing to make a decision or take an action based on the data? My example concerns environmental decision making; in chemistry or biology the decision might have to do with a drug or medicine.



"At the end of the day, however, it is the generation of internal visualizations that is of the greatest significance in science education."

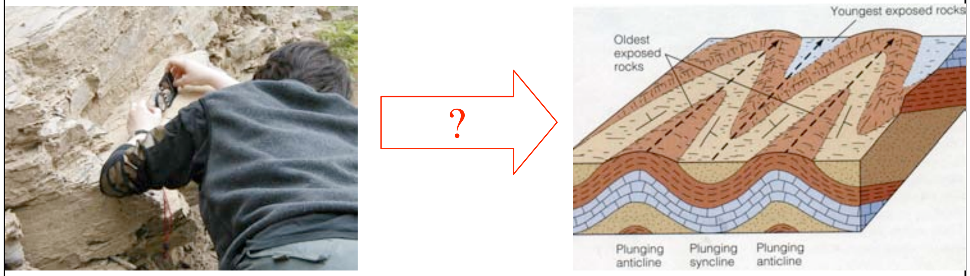
(John K. Gilbert,
Visualization in Science Education, p.2.)

OK, so how do we foster "generation of internal representations"?

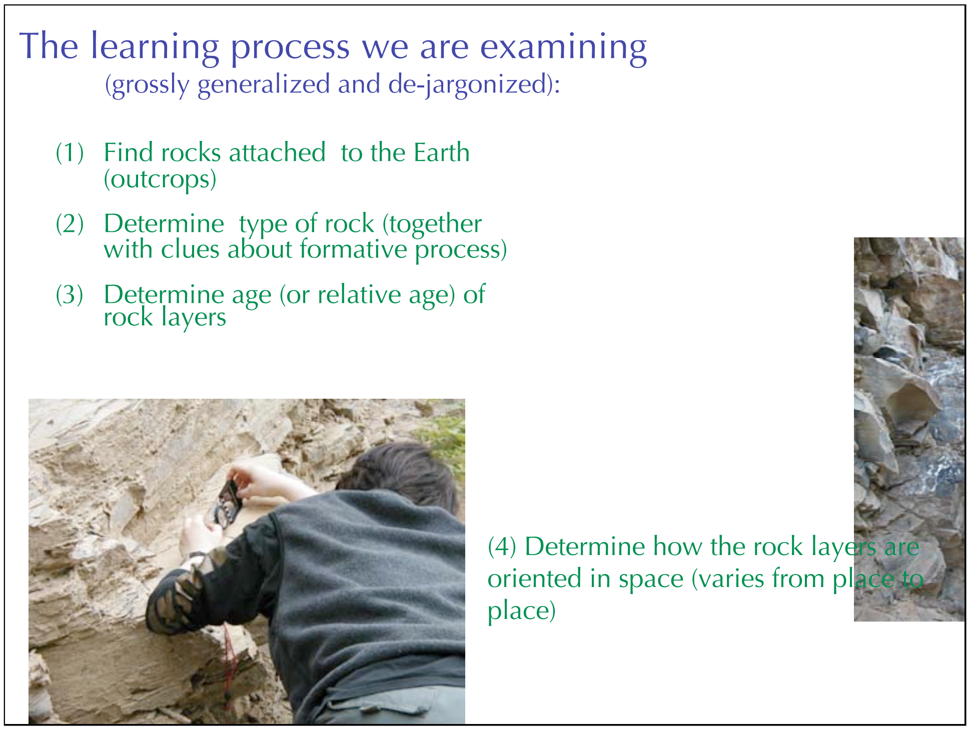
… accurate, functional internal representations, constructed from scratch out of geoscience data and observations?

Now I'd like to move on to another facet of education, drawing inspiration from this quote in the introduction to this book that features chapter by many of you. [Read quote]

How do geology students learn to visualize 3-D geologic structures from the limited information available in outcrops?



This study has to do with how do geology students learn to visualize a 3-D geological structure from rock outcrops.



The learning process we are examining

(grossly generalized and de-jargonized):

(1) Find rocks attached to the Earth (outcrops)

(2) Determine type of rock (together with clues about formative process)

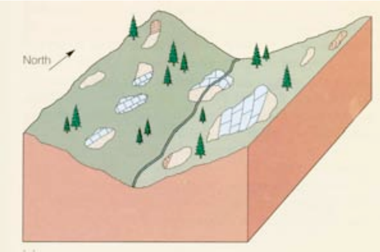
(3) Determine age (or relative age) of rock layers

(4) Determine how the rock layers are oriented in space (varies from place to place)

For people not familiar with field geology, the perceptual and cognitive process we are trying to understand goes like this. The geologist or geology student wanders around out in the field until they find…..

(5) Figure out where the outcrop is located.

(6) Record observations on a spatial representation (aka map)

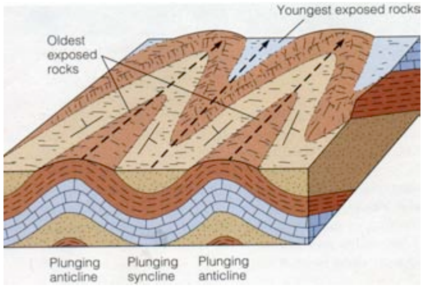


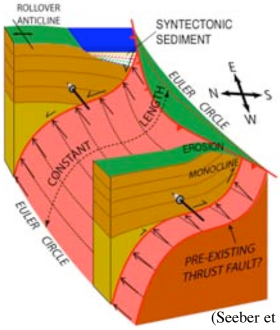
(7) Repeat steps (1) through (6), gathering observations from multiple outcrops thought to be related by formative process.

(8) Form a mental picture of the shape of the rock layers, fault etc….

… taking into account that parts are buried and parts may be eroded …

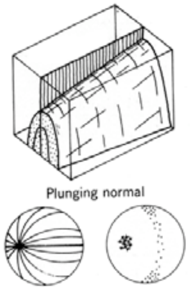
… informed by knowledge of plausible formative processes.

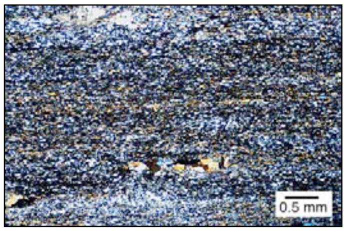


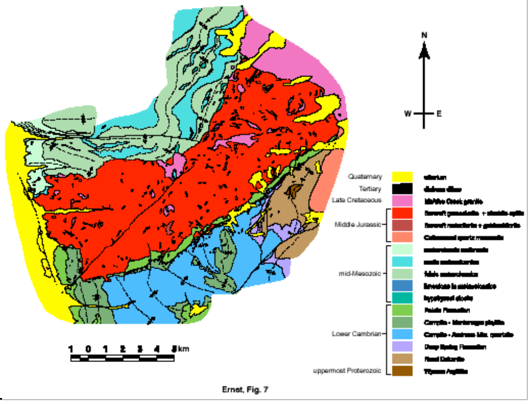


(Seeber et al, in press)

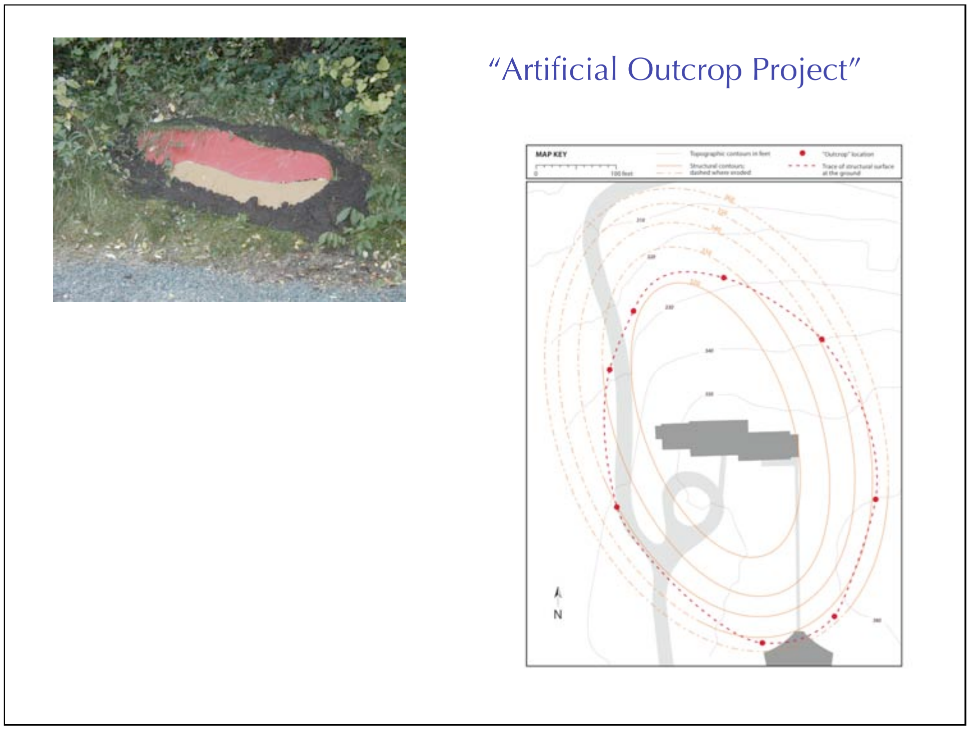
(9) Test mental image of shape/ hypothesis of formative process by further observation.





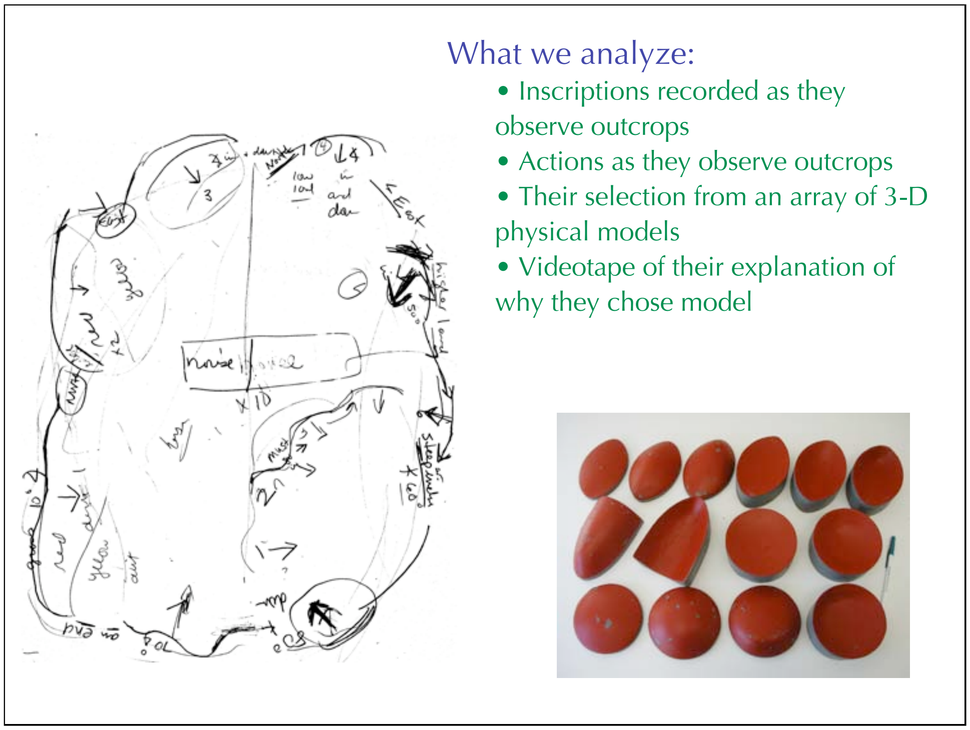


Ernst, Fig. 7



“Artificial Outcrop Project”

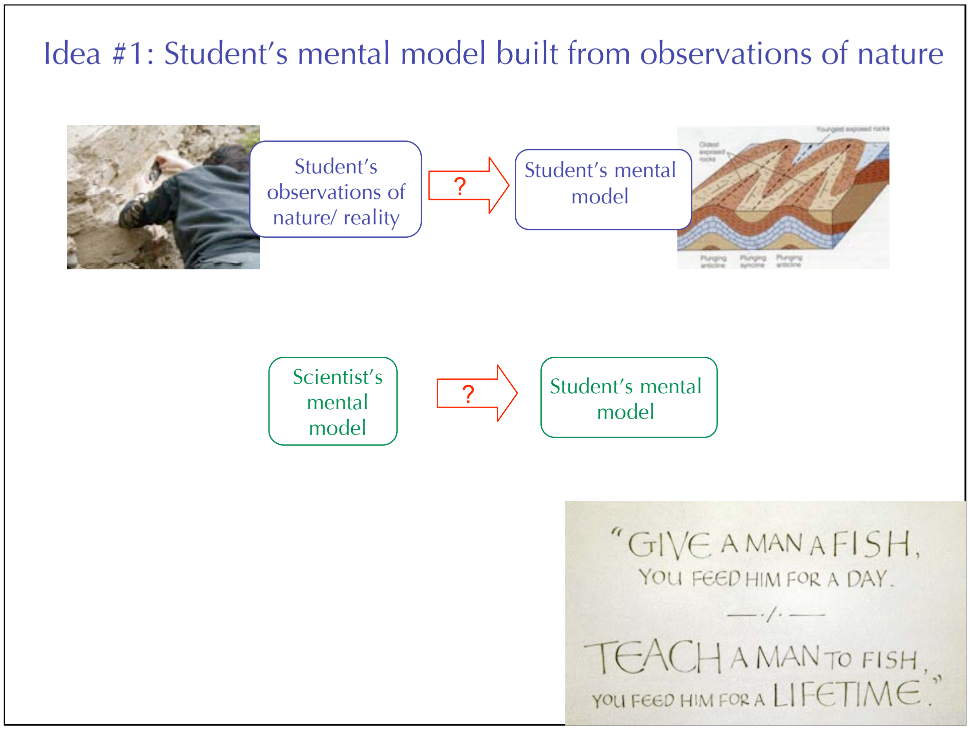
Our study reduces this task down to its spatial thinking essence. We constructed eight artificial outcrops out of plywood, and installed them around our campus. The location and orientation of the outcrops is such that if they really were connected underground they would form an elongate basin 180 meters long, shown by these brown contours. It is not possible to see all of the outcrops simultaneously from any single vantage point. After a brief introduction to the nature of the task, we lead student and experts, individually, around to each of the outcrops, shown by the 8 red dots on the map. We allow them as long as they want to make observations at each outcrop.



What we analyze:

- Inscriptions recorded as they observe outcrops
- Actions as they observe outcrops
- Their selection from an array of 3-D physical models
- Videotape of their explanation of why they chose model

We analyze, what they write down as they observe the outcrops. Sometimes we give them a basemap, sometimes just a blank sheet of paper. We note what actions they made as they observed the outcrops, for example did they look back at previous outcrops or only observe the outcrop in front of them. We ask them to select from an array of 3-D physical models the model that they think could represent the shape of the structure formed by the eight outcrops they have just observed, keeping in mind that the structure is mostly buried and could be somewhat eroded. The 3-D models vary systematically: convex vs concave, round vs elongate, shallow vs steep sided, symmetrical vs asymmetrical. We videotape them as they explain their model selection.



Idea #1: Student's mental model built from observations of nature

Student's observations of nature/ reality

?

Student's mental model

Scientist's mental model

?

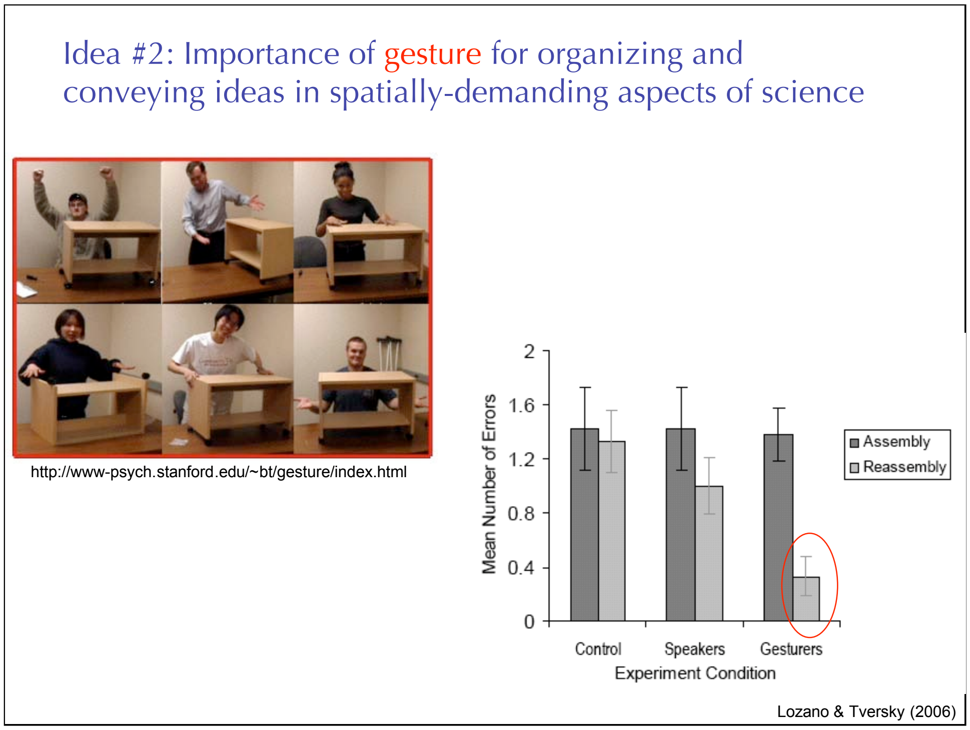
Student's mental model

"GIVE A MAN A FISH,
YOU FEED HIM FOR A DAY.
—·/·—
TEACH A MAN TO FISH,
YOU FEED HIM FOR A LIFETIME."

There are many things going on in this data set. I've picked out three ideas that I hope will resonate with you in all of your different fields. First of all, this study is about a kind of learning in which students are supposed to build a mental model of a 3-D structure from their own observations of the raw material of nature.

[Click.] This is different from many of the talks we have heard in which the focus has been on how can we convey the scientist's mental model in such a clear, engaging, accurate, powerful way that the student will get it. Both questions are interesting, but I'm particularly interested in talking to people who are investigating the first pathway, how students incorporate their own observations of nature and data from nature into their mental visualizations of structures of science.

[click] After all, for those who may grow up to be scientists, they are eventually going to have to build new mental models from observations.



Idea #2: Importance of gesture for organizing and conveying ideas in spatially-demanding aspects of science

http://www-psych.stanford.edu/~bt/gesture/index.html

Lozano & Tversky (2006)

Secondly, and in agreement with several speakers earlier in the week, I'd like to stress how important gestures are in the spatially-demanding aspects of science. In this I'm inspired by the work of Barbara Tversky, who ran a series of experiments in which students had to assemble a television cart, and then instruct others on how to assemble the same cart. Those who were used gesture but no words communicated more effectively that those who spoke, as judged by how well watchers were able to assemble the cart. But most remarkably, the gesturers themselves became better cart-assemblers, as judged by how well they reassembled the cart later.

Video shows student moving two hands symmetrically out and down to show convex shape.

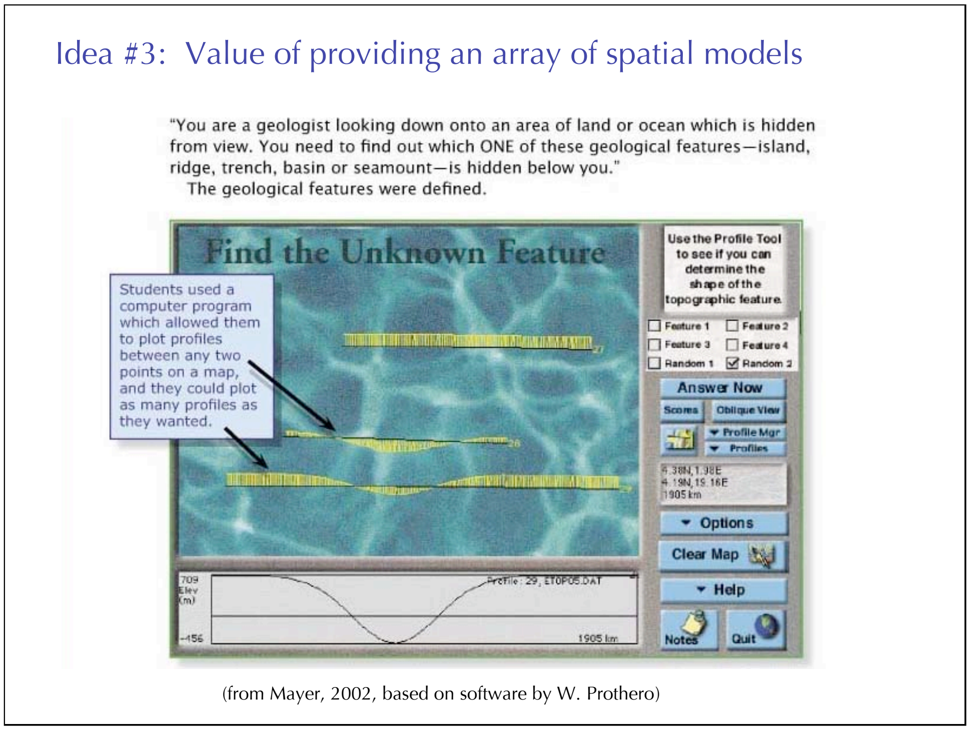
Gestures used to communicate and to organize thoughts.

We see something similar in our data. When students are struggling to form or articulate their ideas about the shape of the buried geological structure, they gesture like crazy, typically using their hands to form or trace the orientation of individual outcrops or their hypothesis about the shape of the structure. [click for video] This person's model is wrong by the way, but the visualization embodied in her gestures is crystal clear.

Video shows student tracking outcrops on map with right hand and on model with left hand.

Gestures/actions used to organize thoughts, and to gather information.

In this case, the student is not communicating with the experimenter, she is totally focused on the task. She appears to be using her gestures to benefit herself, to help organize her own ideas, to compare and contrast her inscriptions on the clipboard with the two spatial hypotheses, the two physical models that remain alive in her deliberations. Notice also how much she touches and feel the model. We see a lot of that in the videos; it seems as though the student using haptic sensory input to gather information about the shape of the model: this one is symmetrical, this one is asymmetrical.



Idea #3: Value of providing an array of spatial models

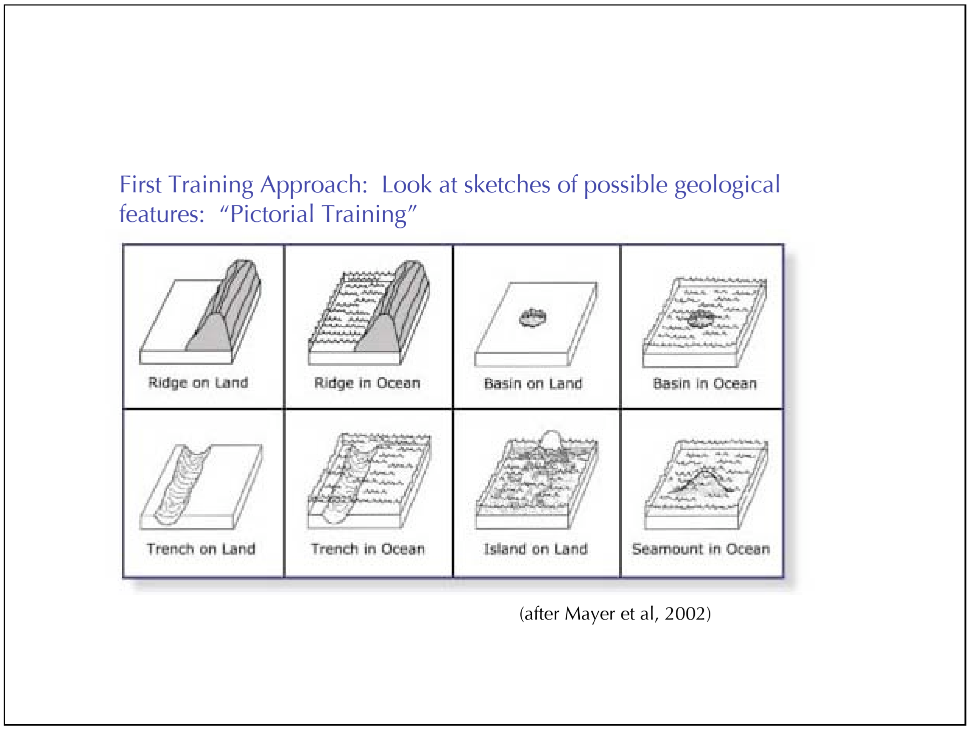
"You are a geologist looking down onto an area of land or ocean which is hidden from view. You need to find out which ONE of these geological features—island, ridge, trench, basin or seamount—is hidden below you."
The geological features were defined.

Students used a computer program which allowed them to plot profiles between any two points on a map, and they could plot as many profiles as they wanted.

Use the Profile Tool to see if you can determine the shape of the topographic feature.

(from Mayer, 2002, based on software by W. Prothero)

The third idea I'd like to share from this study has to do with the value of providing students with a choice of spatial models, or spatial hypothesis as they begin to struggle to make sense out of a new kind of data or observations. I need to digress here into an older study by Richard Meyer and Bill Prothero at UC Santa Barbara. In this study, students were given access to a simulated data set of topographic data. They could drive an imaginary exploration vessel anywhere on their imaginary planetary surface, and the computer would show them a profile of the topography they were passing over. After driving their ship around wherever and for as long as they liked, they would indicate what kind of seafloor feature lay beneath the vessel, a seamount or trench or whatever.

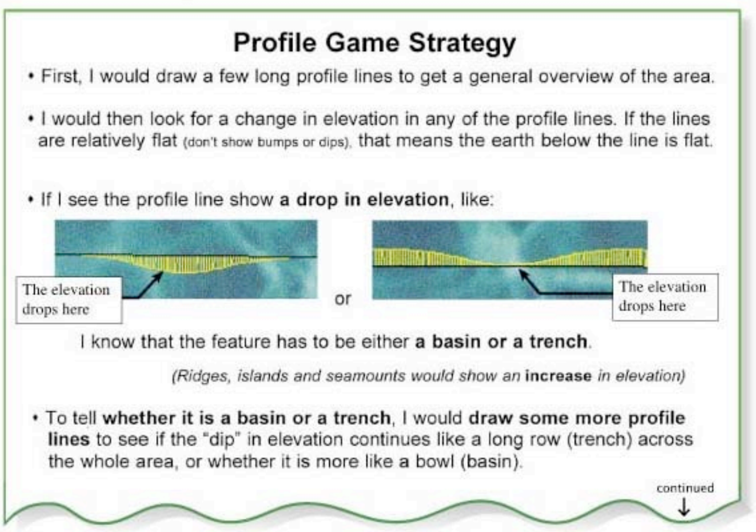


First Training Approach: Look at sketches of possible geological features: "Pictorial Training"

(after Mayer et al, 2002)

Mayer and Prothero tried two educational interventions. In the first, they provided students with a set of cartoon drawings of the possible shapes.

Second training approach: "Strategic Scaffolding"



Profile Game Strategy

- First, I would draw a few long profile lines to get a general overview of the area.
- I would then look for a change in elevation in any of the profile lines. If the lines are relatively flat (don't show bumps or dips), that means the earth below the line is flat.
- If I see the profile line show **a drop in elevation**, like:

The elevation drops here

or

The elevation drops here

I know that the feature has to be either **a basin or a trench**.

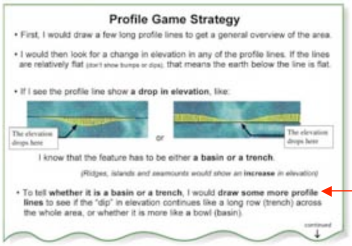
(Ridges, islands and seamounts would show an **increase** *in elevation)*

- To tell **whether it is a basin or a trench**, I would **draw some more profile lines** to see if the "dip" in elevation continues like a long row (trench) across the whole area, or whether it is more like a bowl (basin).

continued ↓

(after Mayer et al, 2002)

In the second intervention, they taught the students a methodical strategy for exploring the unknown terrain.



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(Ridges, islands and seamounts would show an ***increase*** *in elevation)*

- To tell **whether it is a basin or a trench**, I would **draw some more profile lines** to see if the "dip" in elevation continues like a long row (trench) across the whole area, or whether it is more like a bowl (basin).

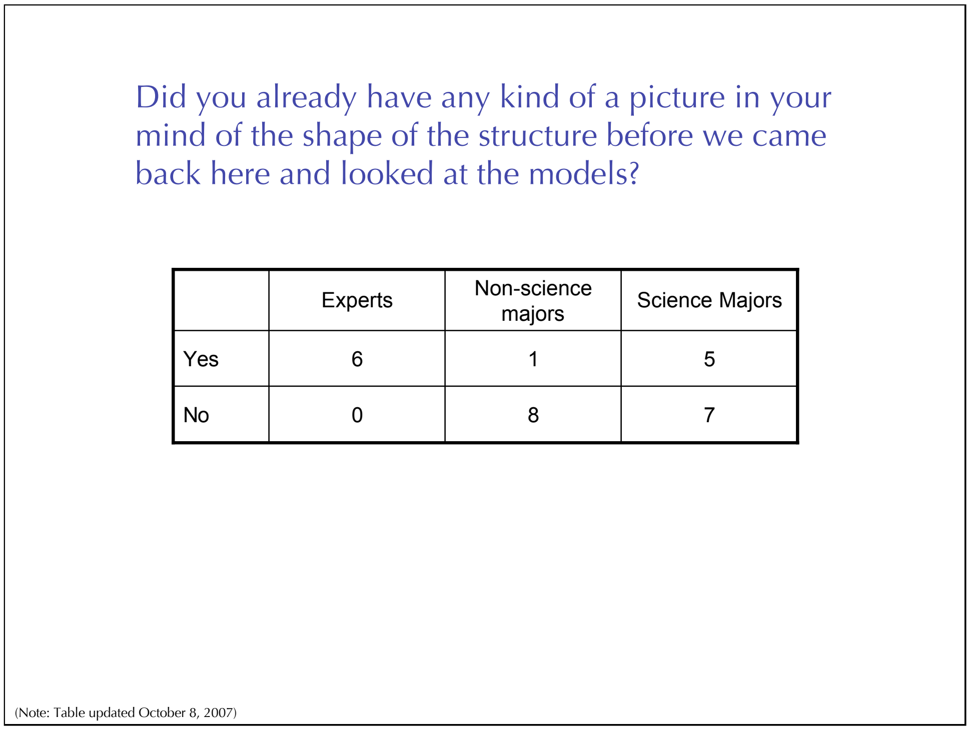
continued ↓

Analyzing and clearly articulating the strategies used by experts…..

…. was not as valuable as providing a visual array of candidate answers.

The students given the cartoons did much better than the students taught the strategy. It wasn't even close. This study bothered me for years. In fact, I considered it a personal affront. My background is in marine geology. I spent 22 months of my life at sea collecting bathymetric data of previously unmapped parts of the seafloor, and I know that the strategy taught in Meyer and Prothero's strategy training intervention is the right way to approach this task. How could showing people those ugly, primitive, little sketches be useful?

Yes, well, I just have to acknowledge that what is the best thing for me, as the expert, is not necessarily the most valuable thing for the non-expert. And now I think I get it, in light of our findings in the artificial outcrop experiment.

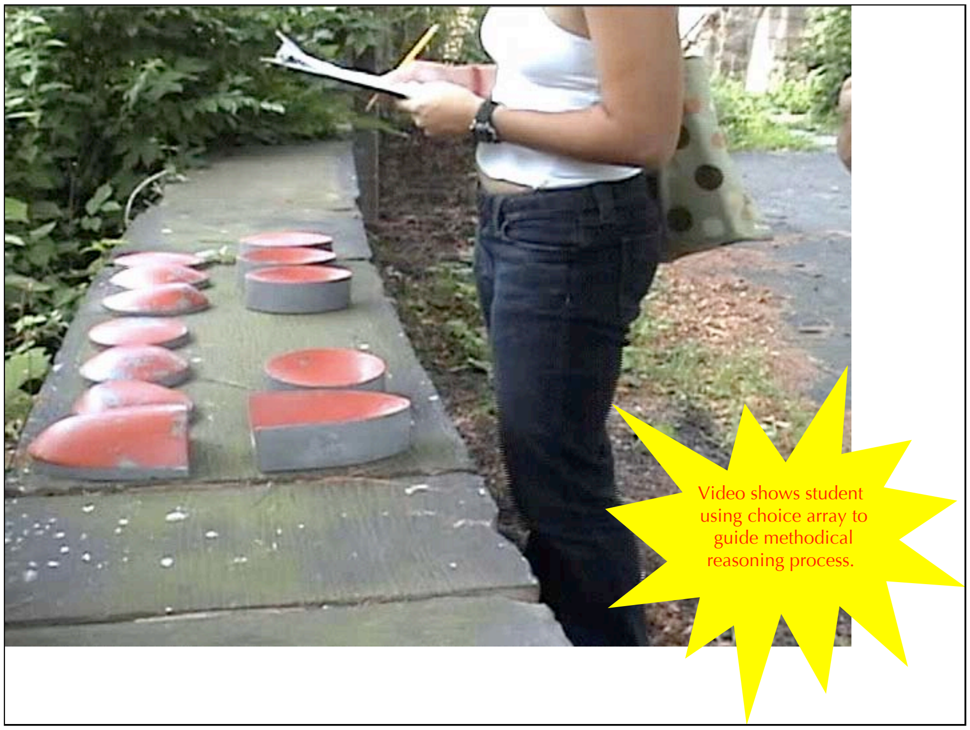


Did you already have any kind of a picture in your mind of the shape of the structure before we came back here and looked at the models?

	Experts	Non-science majors	Science Majors
Yes	6	1	5
No	0	8	7

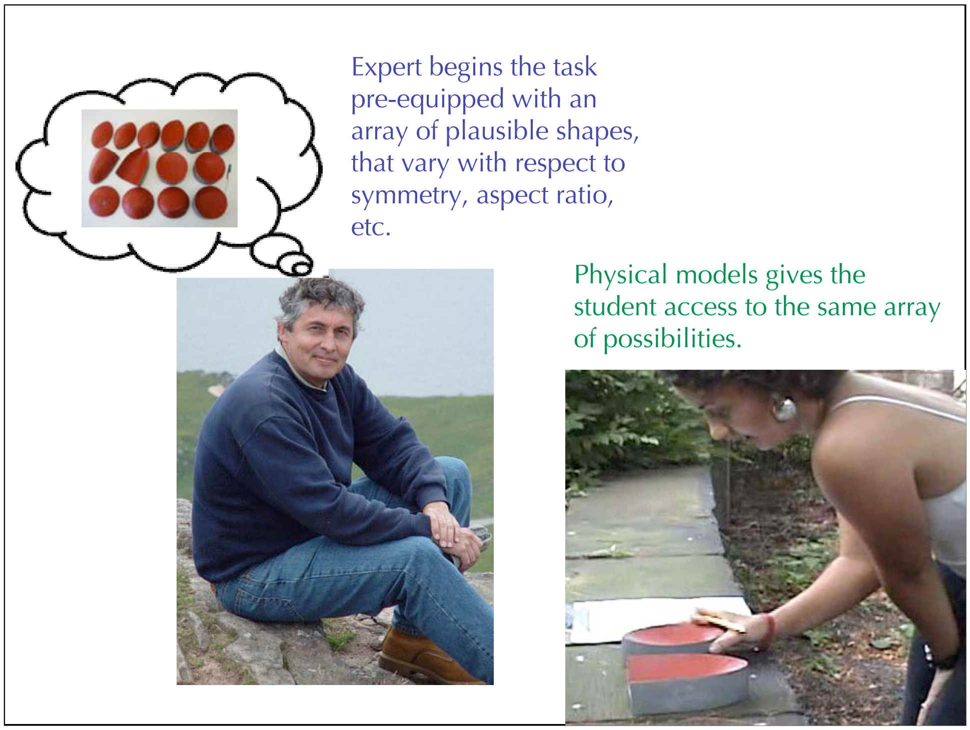
(Note: Table updated October 8, 2007)

So back to our students with the artificial outcrops.   We have recently starting asking them, as the last question of the interview “Did you already have any kind of a picture in your mind of the shape of the buried structure…”   All the experts have said yes. Almost all of the non-science majors said no.   And the science majors are split.



Video shows student using choice array to guide methodical reasoning process.

But the interesting thing is that even the people who said no, they did not have a mental model when they finished looking at the outcrops, when they had the models to refer to, many demonstrated a very methodical, careful, sensible process of interpreting their observations in terms of the structure.



Expert begins the task pre-equipped with an array of plausible shapes, that vary with respect to symmetry, aspect ratio, etc.

Physical models gives the student access to the same array of possibilities.

What I think is going on here, is that the expert comes pre-equipped with an array of plausible shapes. He knows that a structure could be concave or convex (synclinal or anticlinal), symmetric or asymmetric, etc. By putting the array of models physically in front of the student, we catch them up with the expert in this regard. It's not our intention that the student should have to invent the entire theory of synclines and anticlines and basins and dome from scratch, only that they should integrate the particular observations from this particular set of outcrops into a coherent visualization of the shape of this particular structure. I'm eager to try out this form of scaffolding, providing a array of model choices, in a range of different types of activities in which students are first trying to make sense of a new type of data or observations, and I'm interested in talking to others who might be trying this approach.

Take-home Ideas

- Artists' renderings:
  - Dominate textbooks
  - Don't distinguish universal truths from conditional truths
  - Some aspects may propagate throughout society, independent of scientific validity
- Maps:
  - Don't assume *anything* about what your viewers do or do not understand about your data visualization.
  - Do they understand your data visualization? Do they believe your data visualization? Are they willing to make decisions or take actions based on your data visualization?
- Artificial Outcrop experiment:
  - Mental visualization from direct observation of Nature
  - Gestures for organizing and communicating one's spatial thoughts
  - Offer students a choice array of spatial hypotheses (models) to scaffold exploration of a new type of data or observations

Acknowledgements

- Students in “Teaching & Learning Concepts in Earth Science” for critiques of Earth Science visualizations
- Margie Turrin, tally of water cycle images
- Adam Darer, tally of textbook images
- Sandra Swenson, students’ conceptions of bathymetric/topographic digital elevation model
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- Lynn Liben, Shruti Agrawal, and Toru Ishikawa, collaborators on artificial outcrop project
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