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Design Patterns for Instructional Materials that Foster Proficiency at Analyzing and Interpreting Complex Geoscience Data

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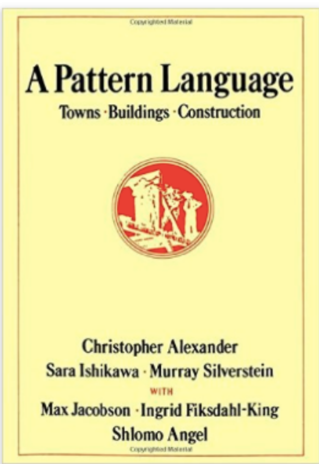
What is a Design Pattern?



The term originated in architecture, and refers to a re-useable solution to a recurring problem or situation.

As applied to curriculum design, a design pattern lays out a sequence of actions to be carried out by teachers and students in an instructional setting. Design patterns are content-independent and can be used again and again for different topics.

This study looked for design patterns that support the learning goal of: *Students are able to use authentic geoscience data to make inferences about Earth processes and decisions about Earth/human interactions*, our geoscience instantiation of NGSS Practice #4: *Analyzing and interpreting data*.

What was our source material?

We analyzed six instructional modules from the InTeGrate project. All were aimed at introductory college level instruction and all were designed following a rubric that required use of "authentic, credible geoscience data." Each module encompassed 6 units, spanning 2-3 weeks of instruction.

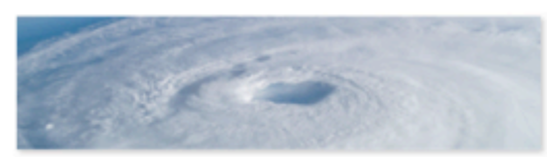
Climate of Change: Interactions and Feedbacks between Water, Air and Ice
Cynthia Fadem, Cindy Shellito, and Becca Walker

Environmental Justice and Freshwater Resources
Adriana Perez, Jill S. Schneiderman, Meg Stewart, and Joshua Villalobos

A Growing Concern: Sustaining Soil Resources through Local Decision Making
Sarah Fortner, Martha Murphy, and Hannah Scherer

Human's Dependence on Earth's Mineral Resources
Prajukti (Juk) Bhattacharyya, Joy Branlund, and Leah Joseph

Living on the Edge: Building Resilient Societies on Active Plate Margins
Laurel Goodell, Peter Selkin, and Rachel Teasdale

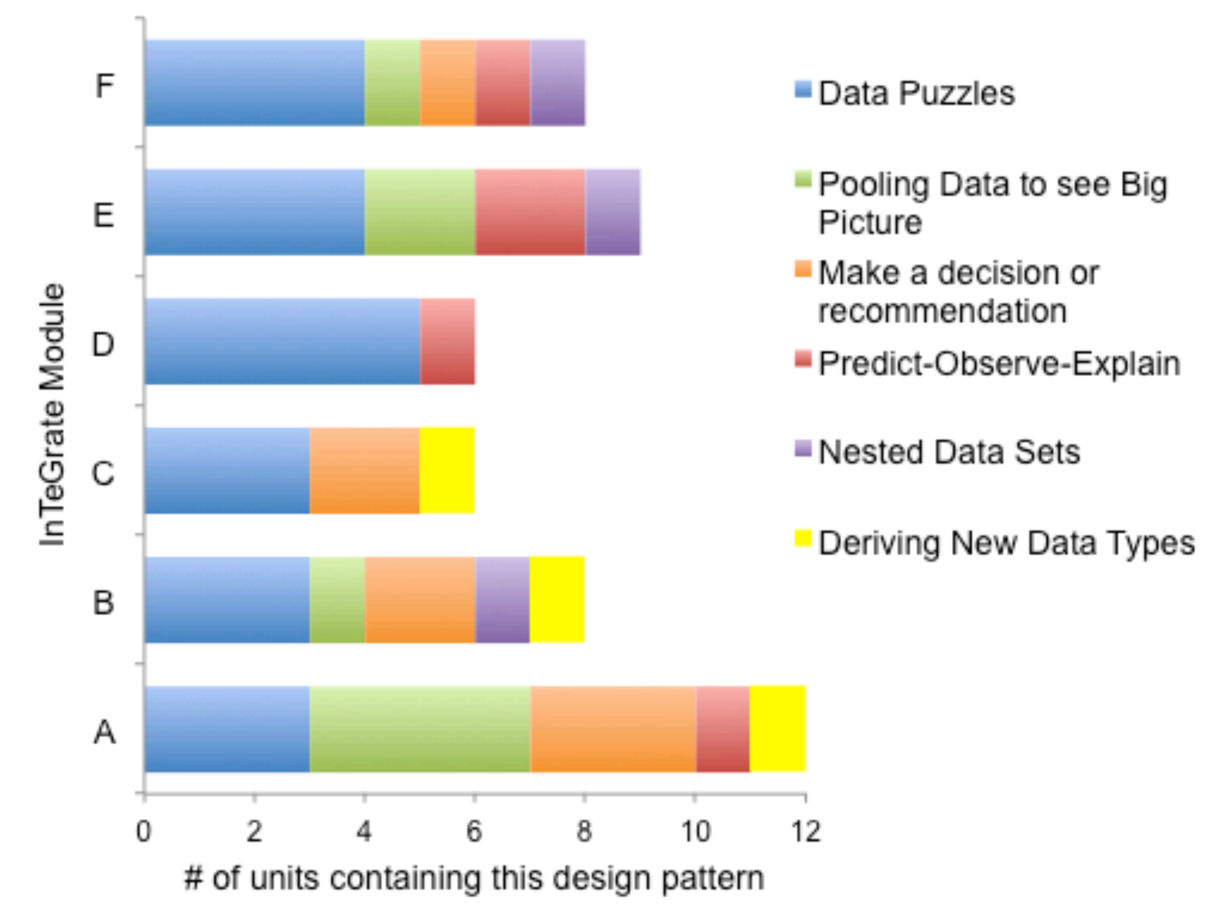


Natural Hazards and Risks: Hurricanes
Josh Galster, Lisa Gilbert, and Joan Ramage

Full modules are at: http://serc.carleton.edu/integrate/teaching_materials/modules_courses.html

What did we find?

We found six distinct design patterns that were used in at least three of the modules. They were distributed across the modules as follows:



Descriptions and examples of each design pattern are across the bottom of the poster.

Data Puzzle

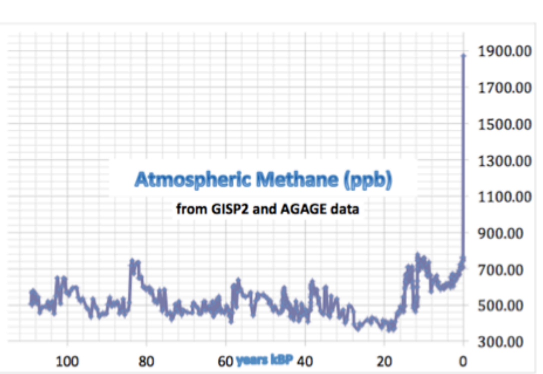
Procedure:

1) Curriculum developer identifies snippet(s) of authentic data that embody an important and widely-taught scientific concept, and develops data visualization(s) that foreground the patterns or relationships emerging from that concept.
2) Students view static data visualization(s) and answer guiding questions about the system represented by the data (not just about how to decode the data).
3) Students experience a rewarding "Aha! moment" of recognition when they see the process they have previously studied conceptually manifest in real world data.

Theory of Action:

The dots, bars, squiggles, and blotches of color of a data visualization look nothing like the conceptual sketches and verbal descriptions by which students are typically introduced to scientific concepts. This type of activity allows students to see the connection between data and concept for clear-cut, unambiguous cases, thus building proficiency at data interpretation and providing an affective reward.

Example:



4. Characterize your graph. What trends do you notice? How does the present differ from the past in terms of atmospheric methane concentration? Be specific.

5. According to your ice core data, when does the most drastic change in atmospheric methane concentration occur? From that date to the present, what is the rate of increase in methane concentration in ppb per year?

[several questions comparing methane with other greenhouse gases]

9. Based on experimental data*, doubling of the current amount of methane in the atmosphere would result in at least a 0.5°C increase in global average temperature. At the current rate of change, when would the atmosphere reach a doubled concentration? How much hotter would Earth be on average at that time due solely to the doubling of methane in degrees C and F?

Climate of Change: Interactions and Feedbacks between Water, Air and Ice, Unit 5, Case Study 5.2 by Cindy Shellito, Becca Walker, and Cynthia Fadem

Pooling Data to See the Big Picture

Procedure:

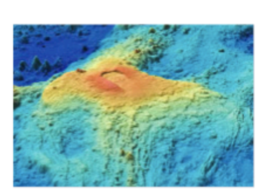
1) Individually or in small groups, students interpret different datasets pertaining to the same real world phenomena.
2) Students share insights from the different datasets.
3) A culminating activity requires students to combine information so as to construct a broader or deeper view of the phenomenon than would be obtainable from only one dataset.

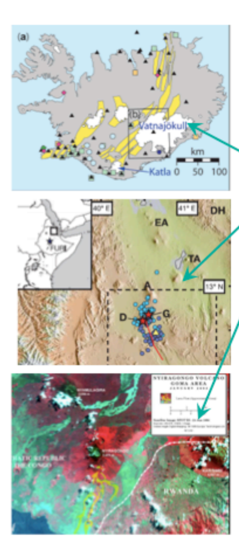
Theory of Action:

- Well-structured cooperative learning activities foster engagement and collaboration skills, and build an understanding that study of something as vast and heterogeneous as the Earth system must advance through collaboration.
- When humans compare and contrast instances that are related but not identical, they can leverage the powerful cognitive process of analogical reasoning to "extract the schema," mapping out what the analogs have in common. Through repeated engagement around similarities and differences, students develop the habit of mind of seeing the world as themes with variations.

Example:

Everyone examines a submarine divergent margin as pre-work.





Small groups examine 3 separate on-land divergent margins (each with multiple data types).

Full class discussion compares and contrasts across field areas.

Table 1: Complete the Submarine Divergent Plate Boundaries column below before

Data Type	Submarine Divergent Plate Boun
Earthquake characteristics (size/depth)	
Volcanism characteristics (erupted products, distance affected)	
Hazards to Humans (how are humans affected — at what scale?	

Table 2 Group Activity (In class): When instructed, examine data provided for your

Plate Boundaries/Summary of Data Provided	Mid-Atlantic Ridge: Iceland (Grimsvötn) Nov 2004	East African Rift: Dabba Volcano, Afar Region Sept 2005
Earthquake Hazards (e.g. specific spatial patterns/depth/size)		

Living on the Edge: Building Resilient Societies on Active Plate Margins, Unit 3, by Laurel Goodell, Peter Selkin, and Rachel Teasdale

Make a Decision or Recommendation

Procedure:

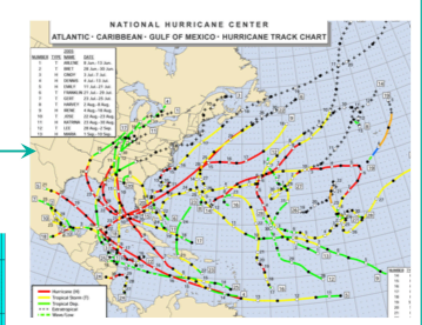
1) Students view data visualization(s).
2) Students are provided with a scenario that requires a decision or recommendation about human action(s) to be taken in regard to a human/Earth interaction.
3) Students make a decision or recommendation, informed by data but also taking into account social, economic, political or other human factors, and justify their choice.
4) (optional) Students prepare a communication for stake-holders who are potential participants in the human/Earth interaction.

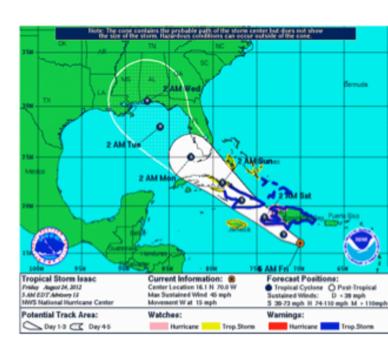
Theory of Action:

Considering data in the context of a consequential human dilemma or challenge is engaging for students. Such activities establish in students' worldview the idea that Earth data can be a tool that contributes to solving high-stake problems for individual humans or for human society. Moreover, students gain experience in balancing science input with input from outside science, such as economics, ethics, equity.

Example:

Students have learned the basics of hurricane formation and the attributes and behaviors of hurricanes, including their characteristics paths across the North Atlantic and Caribbean.





They are given a forecast for a specific hurricane along with the following scenario:

"It is Friday morning and your container ship in Miami is scheduled to sail for Galveston, Texas, this afternoon. It is normally a three-day trip, but a hurricane is predicted to be near Miami by Sunday night (Figure 2). What do you do? Explain the relative risks of staying in port or heading to Galveston on schedule."

The perhaps surprising answer: "Go as soon as possible and get ahead of the storm … By waiting, you risk losing your cargo in the storm. You also put the crew at risk. If the hurricane turns and heads west towards Texas, the ship should already be in port and your ship will be unloaded and safe at least a day in advance."

The scoring guide says that students should use evidence from the data provided, and address the idea of uncertainty in making this difficult decision, with both people and money at risk.

Natural Hazards and Risks: Hurricanes, Unit 2: Hurricane Formation, by Lisa Gilbert, Josh Galster, and Joan Ramage.

Predict-Observe-Explain

Procedure:

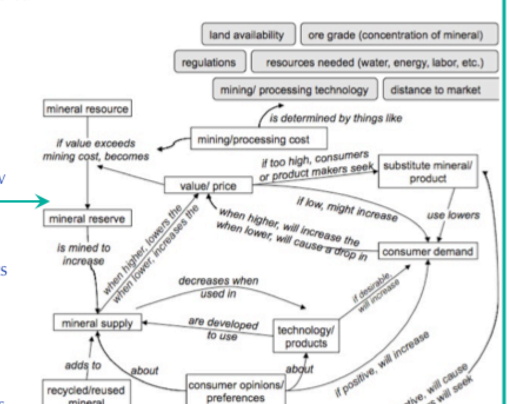
1) Based on either a conceptual model, physical model or computational model, students predict what data from the system under consideration would look like under not-yet-seen conditions.
2) Students examine additional data, looking for the presence or absence of predicted patterns.

Theory of Action:

Working out the predictions attunes students to the relationship between candidate causal processes and observable behaviors in the system under consideration. Then, when they explore the data, they have an idea what they are looking for; they have a specific search pattern in mind, and can draw on the human brain's strong pattern-recognition ability. They also see that reality is not as clean and simple as theory would predict.

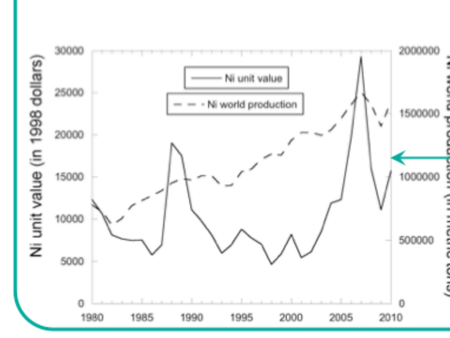
Example:

Previous work familiarized students with a concept map that models how the flow of minerals is impacted by economic and societal factors, such as development of new mineral-using products.



Using concept map model, students predict how certain developments would have impacted price and production of Li and Ni, e.g.:

- 1992: EPA classifies Cd, used in Ni-Cd batteries, as a carcinogen
- 1998-2004: Three new Ni mines open in Australia
- 2007-2009: Global recession.



After making and justifying their predictions, students are given data on Ni and Li prices and production during time span of prediction.

Prompt is "Explain how the data … support or refute your predictions."

Humans' Dependence on Mineral Resources, Unit 2, Activity Option 2.1, The Economics of Batteries, by Prajukti Bhattacharyya, Joy Branlund and Leah Joseph.

Nested Data Sets

Procedure:

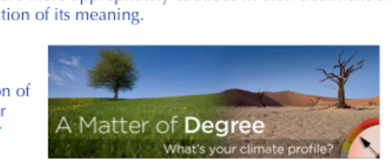
1) Students interpret a local data set. Ideally they collect this data themselves.
2) (optional) Students combine their data with similar data from other students to span a larger population, larger area, or longer time span.
3) Leveraging experience with local data, students interpret professionally collected datasets of the same data type, to expand beyond their local situation to encompass the region, nation or globe.

Theory of Action:

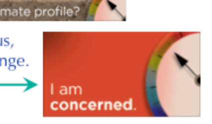
In interpreting their local data, students can draw on their life experience in the locality, and (in some cases) on their experiences collecting the data. Such experiences can provide insights about potential limitations of the data and potential causal processes or influencers in the system under study. When they move on to interpreting the regional, national or global datasets, students carry these understandings with them, and thus are more appropriately cautious in their treatment of the data and more insightful in their interpretation of its meaning.

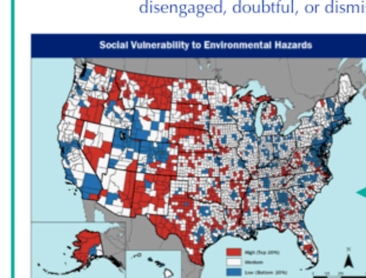
Example:

As pre-work, students take an online version of the "Six America's" survey on "What's your climate change personality?"



Survey categorizes respondents as alarmed, concerned, cautious, disengaged, doubtful, or dismissive with respect to climate change.





Still as pre-work, students categorize themselves and their community according to population characteristics that affect vulnerability to environmental hazards (e.g. age, education.)

As students enter classroom, they find the six climate change personalities written on the board. They enter a tally mark next to their own type. Tallies are converted to percentages.

As full class, students compare and contrast class data with national data, hypothesizing about source of differences.

Climate of Change: Interactions and Feedbacks between Water, Air and Ice, Unit 6, Adapting to a Changing World, by Cindy Shellito, Becca Walker, and Cynthia Fadem

Deriving a New Data Type

Procedure:

1) Students begin with empirical data or observations. With step by step scaffolding, they perform a series of manipulations or calculations with the data.
2) At the end of the procedure, they have a new data type, a "derived data type" used by scientists.
3) Building on their insights about the derived data type, students then interpret a data set of the derived type and use it to make inferences or decisions.

Theory of Action:

Students may have more tendency to "believe" or have confidence in the derived data after going through the procedure. They may have have a deeper understanding of the derived data type and produce more insightful inferences from their examination of the derived data set. Finally, students might better understand the limitations of the derived data type and avoid using it inappropriately.

Example:

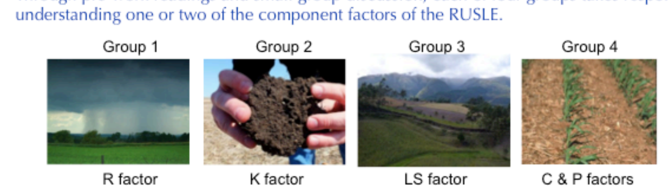
The target derived data type is the "Revised Universal Soil Loss Equation" or RUSLE. RUSLE is used to estimate the average soil loss from a field or region in units of tons per acre per year.

Estimated average soil loss = R*K*LS*C*P

RUSLE is calculated by combining a set of complex, empirically obtained factors.

- R = rainfall and runoff erosivity factor
- K = soil erodibility factor
- LS = slope length factor (landscape)
- C = cover management factor
- P = support practices factor

Through pre-work readings and small group discussion, each of four groups takes responsibility for understanding one or two of the component factors of the RUSLE.



In full-class discussion, each group teaches the rest of the class about their RUSLE factor. Short thought experiments are used to consolidate understanding of how the RUSLE factors interact.

Keeping all other factors the same, if a farmer changes crop rotations such that contribution of the C factor decreases by one third, what would that do to the erosion rate (average soil loss)?

[time passes]

As the summative project for the module, students create an evidence-based agricultural fact sheet for farmers in their region. Among other things, the fact sheet is to discuss regional soil erosion rate (RUSLE), the predicted impact of climate change on soil erosion rate, and recommendations for agricultural practices that can mitigate soil loss.

A Growing Concern: Sustaining Soil Resources through Local Decision making, Unit 5/6, by Sarah Fortner, Martha Murphy, and Hannah Scherer.