Fossils, photovoltaics and misconceptions: The challenges of learning (and teaching) science beyond the classroom

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Learning across a lifespan

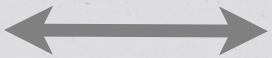
- **Only 14%** of a student's time is spent in the classroom. (About 33% is spent sleeping.)
- **Learning is learning**...but it happens at different times in many different places
- 'informal learning', 'non-formal learning', 'free-choice learning'

What is *Informal Learning?*

- Often used to describe a **museum-based experience**
- Describes participation in **non-school activities** that have an inherent educational value.
- Typically **self-paced**, voluntary, exploratory
- Guided by learner **choice**

Formal vs. Informal

Specific goals, primarily *cognitive*	Broad goals, often both *affective* and *cognitive*
Learner assessment	No learner assessment
Structured and sequenced	Unstructured
Compulsory	Voluntary
Solitary	Social interaction
Fewer unintended outcomes	Many unintended actions
Decontextualized knowledge	*Contextualized* knowledge



How do people 'use' museums?

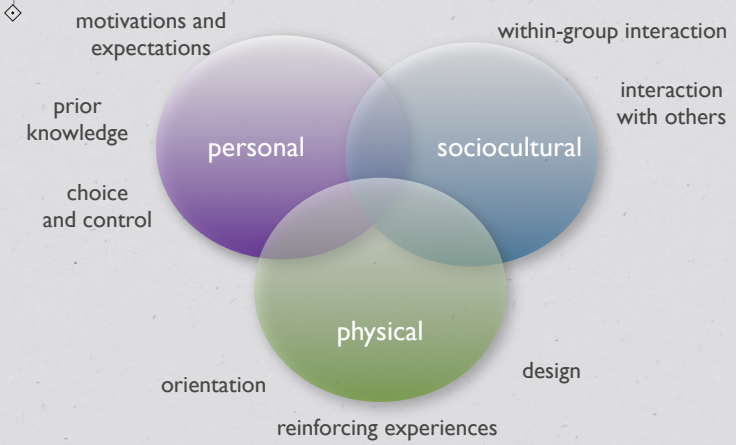
Some typical visitor behaviors:

- A typical exhibit stop may last 10-40 seconds
- Visitor time within an exhibition space is measured in minutes (10-15 min, on average)
- Visitors tend to turn right, when given the opportunity
- Visitors tend to stick to the sides, and follow the main path

Research and evaluation studies **link observed behaviors to likelihood of learning**

- **IF** the goal of an exhibition is to inform, to show, *to teach*…
- **THEN**, you must consider the learner--the *visitor*.
- A visitor's (learning) experience is shaped by different contexts:
  - Physical
  - Sociocultural
  - Personal

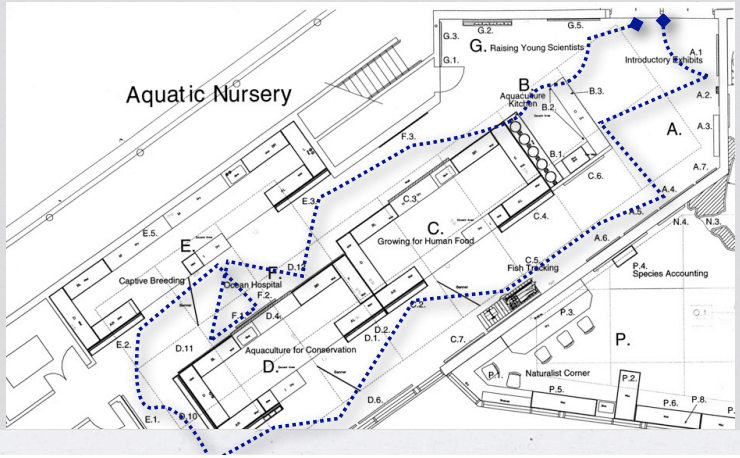
Contextual Model of Learning



Exploring the personal context

- Understanding what the visitor *brings* is important if educators or designers wish to facilitate a learning experience (not unlike the classroom!)
- Must consider **choice**, **motivations** & **prior knowledge**

What do they do?
The role of choice



Why go to a museum?
The role of motivation

- People visit museums for a variety of reasons: education is usually part of the rationale, but may not be the most important (social, lifespan, convenience, etc.).
- Studies have shown that visitors with strong '**education**' agendas **OR** strong '**entertainment**' agendas are more likely to demonstrate learning as an outcome of their experience.

education ⇄ **entertainment**
entertainment ⇄ **education**

Why go to a museum?
The role of motivation

Visitor Identities influence learning

- **Explorers:** Curiosity-driven, seek to learn more about whatever they might encounter
- **Facilitators:** Focused primarily on enabling the experience and learning of others in their group
- **Professionals/Hobbyists:** Feel a close tie between the institution's content and their profession/hobbies
- **Experience seekers:** Get satisfaction from the idea of visiting this particular site
- **Spiritual pilgrims:** Seek a contemplative and/or restorative experiences

What do they already know?
The role of prior knowledge

- **Constructivist perspective**—understanding builds on prior knowledge.
- Learning outcomes depend on where the learner starts
- There are very few published studies have looked at **museum visitors'** prior knowledge of **science concepts**.
- These are sometimes done as part of **front-end evaluation**, but findings are often left unpublished or deemed 'ungeneralizable'

Science Center Visitors' Understanding of Renewable Energy

GREAT LAKES Science Center

Research Questions

1. To what extent do visitors feel knowledgeable about renewable energy, including solar energy?
2. To what extent to visitors understand how solar (photovoltaic) panels work?
3. To what extent do visitors see solar energy as a viable alternative to traditional energy sources (fossil fuels) and what rationale do they use to support their decision?

So why THESE questions?

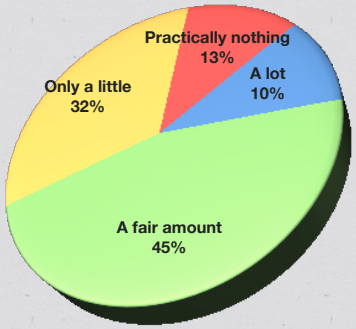
The Science Center became involved in a project advocating the use of wind energy in northern Ohio. They received funding to install a wind turbine and create exhibits related to this technology. The turbine was installed in May 2006.

In June 2007, a solar portico was installed. The science center was interested in knowing how visitors would react to these efforts. What were visitor attitudes toward renewable energy? What did they know? Did they think renewable energy had a place in Northern Ohio?

Methodology

- **Phase 1. Visitor interviews** at the Great Lakes Science Center
- **Phases 2 and 3. Online survey.**
  - Open and closed ended questions, informed by Phase 1
  - 2 populations: Science Center members (N=441) & local teachers (N=125)
    - 88% white; 87% with college degrees or higher; 70% ages 36-55

'How much do you feel you know about energy issues and problems?'



The results for this study resembled those reported by NEETF (2002) in their study of over 1500 adults.

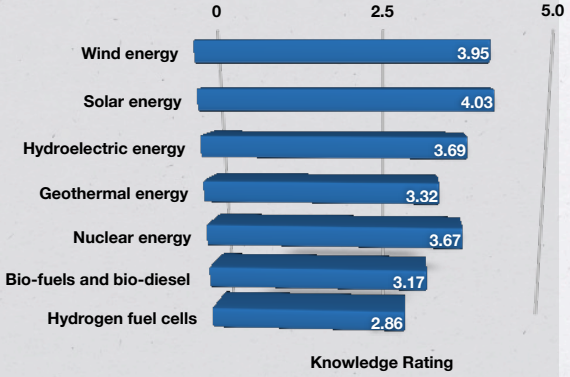
The NEETF report suggested that adults overestimate their understanding of basic energy concepts, as participants scored poorly on a test of energy knowledge.

'How would you describe your understanding of how we get electricity from each of these sources?'

Respondents were asked to rate their knowledge on a scale of 1 (low) to 5 (high).

Results suggest higher comfort levels with wind and solar energy.

[Only members were asked this question; N=441]



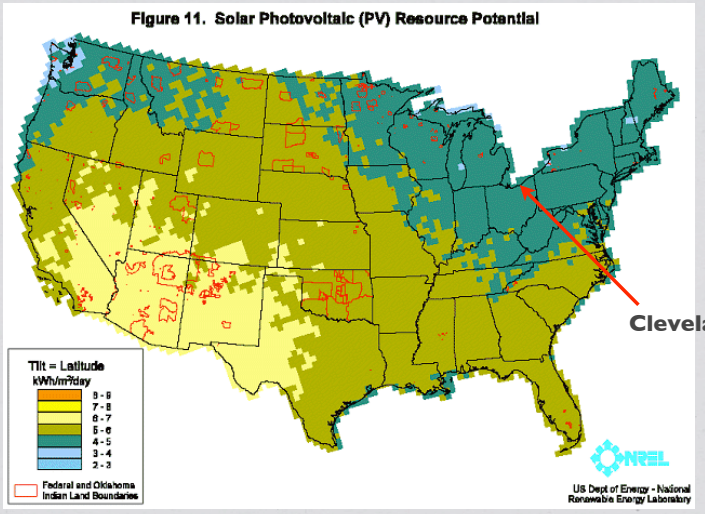
'What comes to mind when you think of solar energy?'

Category	*Description*	*Frequency (N=566)*
Examples	panels, houses, road signs, calculators, yard lighting, spacecraft	**41%**
Cost	expensive, money-saving in long-term	**19%**
Brief description or definition	energy from the sun', 'converting the sun's energy to generate electricity'	**16%**
Explanation	'sun rays beat down on solar panels and transfers it into energy'	**16%**
Local feasibility	why it might or might not work in Cleveland	**14%**
Locale or climate conditions	good for certain places, used on rooftops, in the Southwest	**13%**
General benefits	'we need to explore this', underutilized resource	**13%**
Efficiency/reliability	included both positive and negative comments	**9%**
Environment	benefits to environment, concerns over materials needed	**5%**
Political issues	incentives or obstacles to using more solar energy	**3%**

'Is Cleveland a good place to generate energy from the sun?'

'Is Cleveland a good place to generate energy from the sun?'

***evidence-based* responses** (73%)	
It's cloudy in Cleveland a lot of the time, so generating solar energy may not be worthwhile.	23.1%
The days are too short in Cleveland during the winters, so generating solar energy in this area may not be worthwhile.	6.3%
I'm **not sure** how much sunlight is really needed to make generating energy worthwhile.	**27.1%**
Using the sun as an energy source is just not cost-effective compared to the traditional energy sources we use now.	2.7%
You don't need a lot of sun to generate energy, so Cleveland is as good a place as any.	3.4%
There's enough sun in Cleveland to make solar energy a good alternative.	10.3%
***need-based* responses** (23%)	
We need to explore alternatives to traditional energy sources to better care for the environment.	15.6%
We need to explore alternatives to traditional energy sources to reduce our dependence on foreign oil.	6.9%



'How are solar panels, like the one shown here, able to harness the sun's energy?'

← This image accompanied the survey question.

550 people responded to this open ended question

video

Findings: Misconceptions related to solar panels

- **Only 14% of respondents** were able to give a complete or at least partial explanation of how a solar panel/cell worked (e.g. converting light energy into electricity).
- This **increases to 21%** if explanations that describe 'the energy from the sun' being converted to electricity are included.
- Several misconceptions regarding the function of solar panels also emerged.

Mechanisms reported for solar panels

***Light* transformed to electricity**	**14.4%**	
detailed	2.9%	The absorption of light energy by semiconductor materials causes the excitement of electrons. Electrons that escape their shells are then directed together to create a flow of electrons. #409
general	11.5%	The panels transfer the light into electrical energy. #480
***Energy* transformed to electricity**	6.3%	They save the energy from the sun & convert is to electricity. #224
***Heat* absorbed and transferred**	**8.7%**	The radiant heat is collected on the panels and is used to heat water. The water circulates through the area to be heated and gives off heat. #358 The panels heat up from the sun and emit heat to the inside of the building #438

Mechanisms reported for solar panels

Heat transformation	8.7%	The panels and the wire grids in the panels heat up and turn solar energy into electricity. #354 They absorb heat from the sun, and it is somehow converted into energy. #60
***Energy* collected and/or stored without transformation**	19.6%	The sun heats the panel which collects the energy and stores it in batteries to be used at a later point. #326
No response or don't know	**30.9%**	

Did visitors overestimate their 'energy knowledge'?

How much do you know about energy issues and problems?	total responses (N=550)	% describing a photovoltaic mechanism
A lot	64	36%
A fair amount	276	26%
Only a little	196	9%
Practically nothing	23	4%

Emerging Misconception: Storing energy

- About 1/5 of the respondents made mention of storing energy or batteries as part of their solar panel explanation.
- Nearly half of these respondents (or about 10% of the total population studied) suggested that the sun's energy was stored within the solar cell or solar panel itself.

Take in the sun's energy and store it in solar cells. #447

Sun hits panels, cells in the panels store energy, energy is collected (not sure how) from the cells. #128

So What?

Challenges

The results of this study suggest that science center visitors and teachers:

- may **overestimate their understanding** of energy and energy technologies
- have a **wide range of perceptions** and attitudes related to solar energy
- may have **underlying misconceptions** about how solar panels work, which may affect their ability to make informed decisions regarding the implementation of such technology.
- may rely on **intuitive or common-sense understanding** when determining the utility of alternative energy sources.

Implications

- **Advocating the use of solar or other forms of renewable energy** will require helping learners or consumers to reexamine or validate their assumptions about usefulness (e.g. too cloudy in Cleveland for solar energy).
- **Advocating the use of solar or other forms of renewable energy** will require addressing possible misconceptions that may be informing their decision-making
- The results here suggest that **solar energy has different personal meanings for different learners**.
- In order to **better understand the apparent misconceptions** related to solar cells and the use of solar energy, in-depth interviews should be used to clarify the learner's understanding.

Uncovering Visitor Conceptions of Fossils and the Fossil Record

Natural History Museum of Los Angeles County

Page Museum La Brea Tar Pits

UF UNIVERSITY of FLORIDA

The natural history museum and evolution project

- In 2003, the University of Florida began multi-site investigation of natural history museum visitors' understanding of evolution. (NSF ISE 0138030)
- Six natural history museums of varying sizes and locations within the U.S. were used as data collection sites.
- Goal: To gather information related to visitors notions of evolution and related concepts as a way to inform exhibit development.

Methodology

- Visitors to the natural history museums had been asked to **complete a short interview** (10-20 minutes) consisting of three sets of questions that prompted individuals' explanations of fossils, the fossil record, and concepts related to evolution. Interviews were recorded via audiotape and later transcribed.
- The **six original sites:** Natural History Museum of Los Angeles Country, the Page Museum & La Brea Tar Pits, Denver Museum of Nature and Science, University of Kansas Natural History Museum, Florida Museum of Natural History (UF), National Museum of Natural History (Smithsonian)
- Visitors **ages 8 and up** were interviewed.

Findings

- From that investigation, MacFadden et al. (2007) reported only 30% of visitors ages 15 and up were able to explain the process of evolution using a natural selection mechanism. *(via a cheetah word problem)*
- Visitors responses varied by age:

  high school < seniors(55+) < 35-55 < 19-34
- Most visitors (89%) accepted evolution, although this varied slightly according to site (e.g. 80% at KU, 94% at NHMLAC)

Revisiting the data

- **A secondary** analysis was conducted
- Examined a portion of the data set--specifically visitor comments related to **characteristics of fossils** and their **interpretation of fossil evidence**
- Data from **two of the six original sites** was used in this study: the Natural History Museum of Los Angeles Country and the Page Museum & La Brea Tar Pits
- Responses were examined qualitatively for recurring concepts. Categories were established based on the data; response frequencies were also established.

Interview questions used for this analysis

If you were to explain to someone what a fossil is, what would you tell them?

From this poster, can you tell me which of the fossils in general are the oldest and which are the youngest?

Some fossils found in the lower layers are not found in the upper ones. How might scientists explain this finding?

Some fossils found in the upper layers are not found in the lower ones. How might scientists explain this finding?

Research Questions

1. **To what extent are natural history museum visitors able to describe the characteristics of a fossil?**
2. **To what extent are these visitors able to interpret fossil evidence? More specifically, how do visitors explain fossil discoveries using a diagram of rock formations and strata?**

So why THESE research questions?

Why fossils?

- Fossils (and fossil-based exhibits) make up sizable portions of most natural history museum collections.
- Fossils help scientists make sense of the past and serve as critical **evidence for evolutionary theory**.
- 'Fossil' is a **common term** with which many people are familiar--it is conceivable, however, that definitions vary and may or may not correspond with a 'scientific' definition.
- How much visitor prior knowledge can we take for granted? How 'accurate' is that knowledge? (e.g. cladistics)

'How would you explain what a fossil is?'

Six concept categories were established based on **visitors' definitions of a fossil.**

- **Intrinsic properties** -references to the origin and composition of a fossil
- **Process** - references to the processes involved in fossil formation
- **Time** - references to fossil age and/or to the length of time required for a fossil to form
- **Location** - references to locations where fossils are often found
- **Type** – references to specific types of fossil
- **Value & Function** – references to the use of fossils in science and history

Example of coding process

2. Process (2.2 Process of change + 2.3 Mineralization/ Replacement)

3. Time (3.1 General descriptive)

1. Intrinsic Properties (1.1 – Comes from an organism: general organism)

I would describe them as the remains of life of living things uh from long ago – the remains have been um turned into [rock] or something else that has survived all these years, uh and that if you are lucky you can still dig 'em up today and find out about those old dead things.

1. Intrinsic Properties (1.2 Composition)

4. Location (4.3 – Process of being recovered from a location)

6. Value & Function (6.1 Discover more about the past)

Visitor-generated characteristics of fossils

1. Intrinsic Properties - references to the origin and composition of a fossil

- 1.1 Remains of an organism *(Plant or animal)*
- 1.2 Composition *(stone, wood, bone, etc)*
- 1.3 Age *(old, ancient)*
- 1.4 Condition or state *(hard, difficult to handle)*

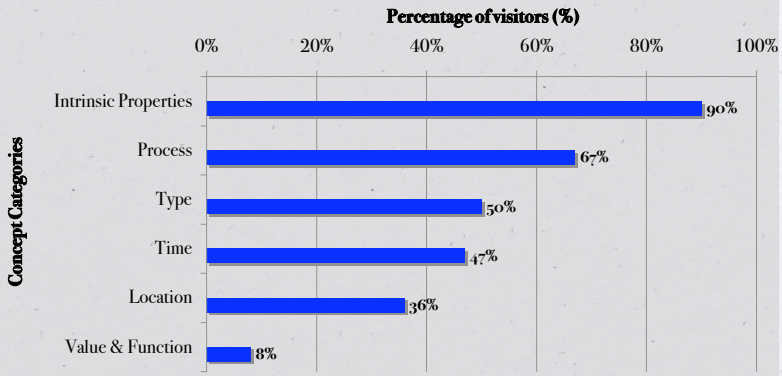
2. Process -references to the processes involved in fossil formation

- 2.1 Process of change/preservation *(preserved, molded into rock, turns into rock over time)*
- 2.2 Process of being buried *(buried in sand or dirt, remains got buried in sediments, layers covered it)*
- 2.3 Mineralization / replacement *(chemical and mineral changes took place; become stone generally of calcium build up I think and minerals going into cells)*
- 2.4 Specific materials that aid process *(sand, mud, tree sap, volcanic ash)*

3. Time - - references to fossil age and/or to the length of time required for a fossil to form

- 3.1 Descriptive *(from a long time ago, old, aged)*
- 3.2 Specific number *(millions of yrs, thousands of yrs)*

Frequencies of conceptual categories



Frequencies of conceptual categories

- On average, visitors mentioned 3 of these 6 categories in their definition of *fossil*–whether adult or child.
- Adults were more likely to mention **process** related to fossil formation--in particular a change process ($\chi^2(1, N=159) = 5.46, p<0.05$)

Concept Categories

Intrinsic Properties

Process

Type

Time

Location

Value & Function

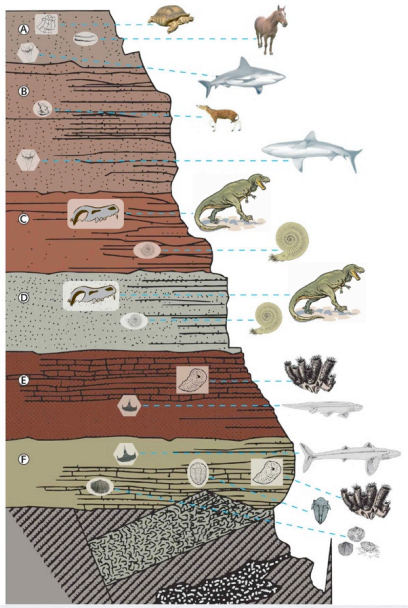
Fossils as Process

Category	% (N=159)
Process of **burial**	32%
Process of **change**	52%
preserved	17%
mineralization	31%

- Overall, 2/3 of visitors mentioned some kind of **process** when describing a fossil
- Over half mentioned some kind of **change** (preserved, mineralization, hardening, etc.)
- Adults were more likely to mention **mineralization**; $\chi^2(1, N=159) = 6.23, p<0.05$).

How do visitors interpret the fossil record?

the law of superposition refers to the idea that over time, newer layers of sedimentary rock will build up on older layers



How do visitors interpret the fossil record? Which are oldest and which are newest?

- most visitors (87% of 169) were able to identify **older layers as lower layers**
- about 35% made specific reference to organisms depicted to help them answer
- of the 22 visitors who **did not** recognize that older fossils were in deeper layers, all but two used images to help decide

Why are fossils in lower layers not found in upper layers?

Response category	Example	% (N=169)
Extinction	They've gone extinct and are not living anymore. (PM46)	57%
Environmental Change	They couldn't keep up with the demands of their environment. Something grew to eat them. (PM75)	33%
Evolution *or* **Organism Change**	Because they evolved. They transformed and changed. (PM40)	23%
Fossil Movement	Could be something that got stuck somewhere and just got shoved down. (NHM4)	12%
Unable to Survive in Different Layers	These look like water animals, so there was probably water right here, but no water up here, so you couldn't find them up there. (NHM22)	10%
Don't know/other		8%
Organism Migration	They weren't there because they didn't live at the other times…they could have lived later, but lived somewhere else. (PM57)	4%
No Fossilization	Maybe the environment was such that they couldn't be preserved? (NHM27)	1%

Why are fossils in upper layers not found in lower layers?

Response category	Example	% (N=169)
Evolution *or* **Organism Change**	The ones in the upper layers look like they've evolved into growing teeth and eating specific types of food and in the lower levels look like fish or animals of the sea. (PM20)	36%
Organism Appearance	A tortoise is more of an evolved animal than (those) from this period…. They weren't around at the time. (PM75)	32%
Environmental Change	A lot of different things changed--climate, whether they were on land or in ocean. (PM13)	22%
Don't know/other		10%
Unable to Survive in Different Layers	Some tortoises lived on land most of the time. And sometimes they would go in water, but mostly they go on land. (NHM50)	8%
Migration	They weren't indigenous and may have migrated. (PM32)	6%
Extinction	Couldn't survive then so they died out (PM 45)	3%
Fossil Movement	…These are later than these, so over time, maybe over time the rocks would have pushed these down (NHM38)	2%
No Fossilization	They never became fossilized back then could have had something to do with what they were made of and what their decomposing bodies were subject to. (PM73)	1%

How do visitors interpret the fossil record?

- visitors used a **variety of different reasons**, and often invoked more than one.
- different patterns of reasons depended on question (bottom-up vs. top-down)
- only about 1/3 (or less) made reference to **organism changes** to account for fossil absence

Object- vs. Process-based Explanations

	Explain why fossils in lower layers are not found in upper layers (N=169)	Explain why fossils in upper layers are not found in lower layers (N=169)
Object-based explanation	12%	2%
Process: **Organism**-based explanation	59%	64%
Process: **Environment**-based explanation	46%	34%

Note that some visitors used **both** organism- and environment-based explanations. In these cases, they often invoked a *causal relationship*:

environment change → organism change

So What?

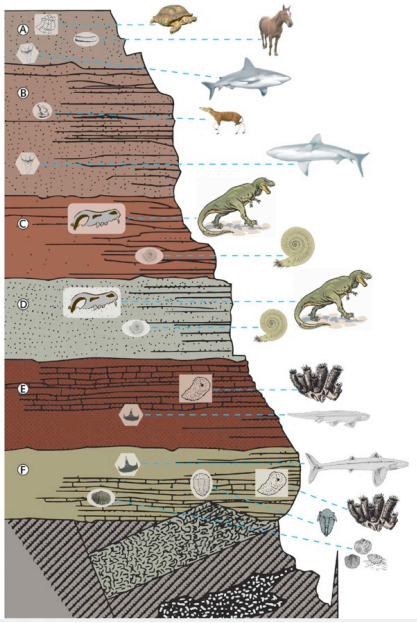
Challenge: Missing Pieces

- **Breadth of visitor responses** seems consistent with the varying ways that 'fossil' is defined by different sources. It suggests that visitors do indeed have some ideas regarding what a fossil is. However...
- Visitors made very little mention of the **rarity of fossils** (i.e. conditions needed to be just right for fossils to occur; therefore many organisms were not fossilized.)
- Only 8% made any mention of the **value of fossils**

  That's how we find out about things long ago, that's how we know about things before humans were even on this earth.(NHM91)

Challenge: Visual Cues

- **Diagram as scaffold**
  - about 1/3 used images to *confirm their ideas* about superposition
  - some led to scientifically accurate response, some not (e.g. dinosaurs are oldest)
- **Diagram as source of cognitive conflict**



Challenge: Species Change

- Many of the reasons given for fossil absence were...*reasonable*
  - used a process-based explantation
  - went extinct, environment changed so animals left, animal didn't exist yet
  - only about 1/3 used **species change** explanations (23% for bottom-up; 35% for top-down)
- **Organism appearance** explanations--may mask creationist reasoning

Implications

- Visitors have a **broad and varied conception of fossils**--potentially many entry points for different learners
- Consider a **focus on process**--a salient feature, but not necessarily well understood. Especially important for children.
- Consider **emphasizing the value of fossils as a scientific tool**

Implications

- **Strata representation may be a useful way to convey time**–yet visitors may still interpret this in terms of existing notions of geologic time and animal origins
- Consider how such displays and fossil specimens might be used to **move visitors from intuitive reasoning to evidence-based reasoning**.

Only part of the puzzle…

video