Developing assessments of geological thinking and reasoning and studying their affordances for studying spatial cognition

Dr. Janice Gobert
jgobert@wpi.edu

Associate Professor,
Social Sciences Dept.
& Computer Science
Dept.

Co-Director,
Learning Sciences &
Technology Program

WPI

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Some concepts addressed this week

- Knowing your user
- Change blindness
- Cognitive load
- Peer learning
- Spatial skills
- Measuring transfer

Questions for you to ponder….

- How do you know students are learning what you think they are learning?
- Who is falling through the cracks and how do you know?
- How do you know students are transferring skills acquired in one context to another?
- How do you guide learners to learn (really learn) what you want them to learn?

My program of research

- **How people learn with rich visual representations to do reasoning, make inferences, solve problems, etc.**

  Key here is to:
  - **Find exemplary domains**
  - **Design ecologically valid tasks**
  - **Develop appropriate methods and items for collecting and analyzing data**

Program of research, cont'd

- **How to best support learning with rich visual representations.**

Key here is to:

- **Develop assessments that can *differentiate* amongst students in terms of their learning**

- **Develop assessments that can *capture student's learning processes* and link these to conceptual learning outcomes–**
  - **called *performance assessment.***

Today I will…

1) Present some important concepts in characterizing learning with visual representations in

- highly 3-D domains, e.g. Geology, Architecture, and/or
- semantically-rich domains, e.g., Physics, Biology, Chemistry.

2) Describe some work to illustrate techniques used to study learning. Broad range of these with *differing methodologies* presented here

- bring to the fore some important Cognitive Science constructs and some key assessment ideas.

Framework for Cognitive Research in Visual Domains

- **Regarding learning processes for visualizations, learning *is viewed as an active and constructive process.***
- **View largely influenced by "Levels of processing" (Craik & Lockhart, 1972):**

- the *nature of a learner's processing of the target material largely determines the learner's memory representations, reasoning, etc. for that material. **

- ***Characterizing learning processes and their resulting conceptual understanding is central in the Learning Sciences.***

Cont'd

- The levels of processing framework, originally developed for text, has been shown to be applicable with complex visual stimuli.

- Complex or semantically rich visualizations
  - i.e., those with domain-specific symbol systems
  - require a conceptual knowledge base
  - (different from simple, iconic representations like stop signs).

What's special about visualizations from an information-processing perspective?

• **Comprehending or interpreting complex visualizations is difficult because**

…. all the information is presented to the learner *simultaneously*.

• **This is in contrast to textual information sources in which the information follows the structure of the text (Larkin & Simon, 1987).**

- Thus in the case of text, knowledge acquisition follows the structure of the text.

- Clearly not possible for visualizations; then what guides knowledge acquisition?

Information processing (cont'd)

Differences in representational format have direct ramifications on students' information-processing…

- when all information is presented simultaneously, prior knowledge is needed to guide knowledge acquisition.

- what if students lack prerequisite knowledge and skills? (addressed later).

In terms of information processing, visualizations & simulations can provide…

- Perceptual cues which supports rich inference-making (and these inference-making processes may differ from those used on textual information).

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Gobert, J. (2005a) in In *Visualization in Science Education*, J. Gilbert (Ed.), Springer-Verlag Publishers, Dordrecht, The Netherlands.

Information-processing, cont'd

Thus, there is a continuum to the degree of *degree of visual isomorphism* to the objects/processes represented by various types of informational formats.

- **Textual representations describe in words various aspects of science phenomena--non-isomorphic to the things they represent.**
- **Diagrams/illustrations represent spatial structure, but are static.**
  - **inferences are required to reason about dynamic processes.**
- **Models and simulations represent objects' spatial structure as well how they function dynamically or over time.**

Student Difficulties in Learning from Visualizations

Simply providing a diagram or model as an adjunct to text does not facilitate or promote deep understanding because:

- increased *cognitive load* on learners (Sweller, et al, 1990) particularly when the students do not recognize that the "things" being described are the same (e.g. a text and a graphic; Gobert, 1994) .

- students *lack the necessary domain knowledge* in order to guide their search processes through diagrams in order to understand the relevant information you want them to acquire (Lowe, 1989, 1999; Head, 1984; Gobert, 1994; Gobert & Clement, 1999).

How does expertise fit in?

- B/c visualizations present all information simultaneously, *prior knowledge* is critical in guiding knowledge acquisition.
- Not only do experts have more knowledge but experts represent knowledge in ways that are important to tasks in the domain.

Expertise in visual domains

- **Expert-novice studies have been conducted in:**

- **electronics (Egan & Schwartz, 1979),**
- **engineering (Vicente, 1991, 1992; Bedard, 1993)**
- **architecture (Akin, 1979; Chase & Chi, 1981; Gobert, 1989; 1994; 1999),**
- **geographical map reading (Ormrod et al., 1986; Gilhooly et al., 1988; Thorndyke & Stasz, 1980), and**
- **topographical map reading (Chang et al., 1985).**

Expertise

• **Experts in visual domains have domain-specific schemata**

- perceptual and cognitive structures evolved through experience
- especially adapted for performance in their respective domain (Brewer & Nakamura, 1984; Schank & Abelson, 1977; Rumelhart & Norman, 1975).

- **Schemata influence the <u>amount</u> and <u>manner</u> in which information is processed and encoded in memory**
  - account for the superior recall and inference-making by experts (Chang, Lenzen, & Antes, 1985; Gilhooly et al., 1988; Head, 1984).

- **How to promote deep learning in students who (of course) lack significant amount of prior knowledge….?**

Model-Based Teaching & Learning

- **Model-based learning, a synthesis of cognitive psychology and science education…**
  - **Involves formation, testing, and reinforcement, revision, or rejection of mental models.**
  - **Mental modeling building has been used as a pedagogical framework in many domains including geology to promote students' deep understanding of complex causal processes, e.g., convection (Gobert & Clement, 1999; Gobert, 2000).**
  - **For Geoscience, deep understanding requires the *integration* of spatial, causal, temporal knowledge into a rich mental model.**

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Gobert, J. & Buckley, B. (2000). *Int. J. Science Education*, *22(9),* 891-894.

Model based learning involves a dialectic between internal and external models

Cognitive processes act on mental model. Dialectic b/n internal and external model (Norman, 1988)

Mental model, i.e., internal representation (Johnson-Laird)

External Models, i.e., simulations, Google Earth materials

Mental model development is influenced by student characteristics:

-- Prior knowledge
-- Visualization skills
-- Inquiry skills

Affordances of a representation depends on student characteristics

Affordance

First used by J.J. Gibson (1977), a perceptual psychologist

- **what is made possible for the learner, etc. INDEPENDENT of the learner's skills, knowledge, etc.**

D. Norman, (1988, The Design of Everyday Things)

- **From HCI community extended this**
- **success of affordance is DEPENDENT on learners' skills, prior knowledge, etc.**

To date, 2 types of studies

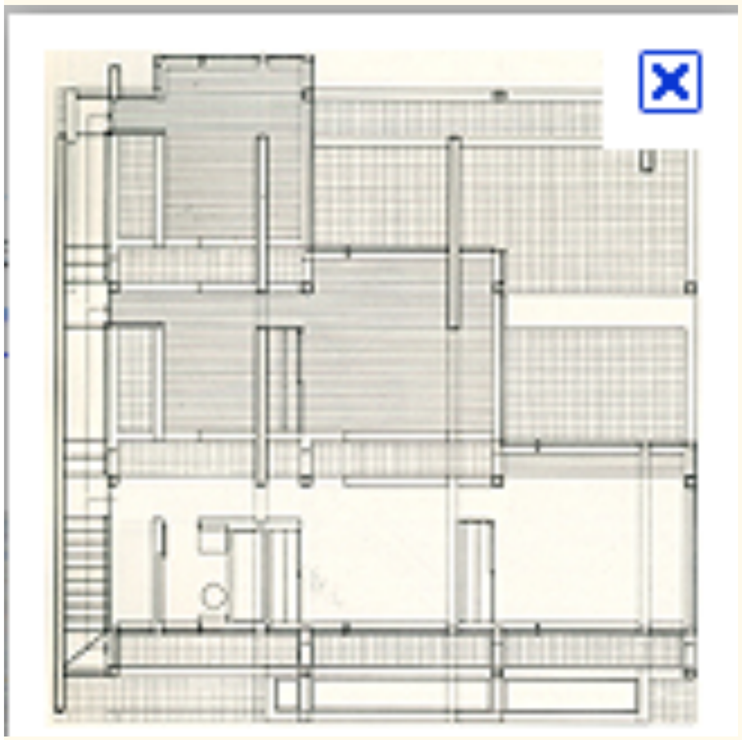
- **Studying the *affordances* of learning with representations of different kinds, in different domains, etc.**
- **Studying how to support students' in learning with representations.**

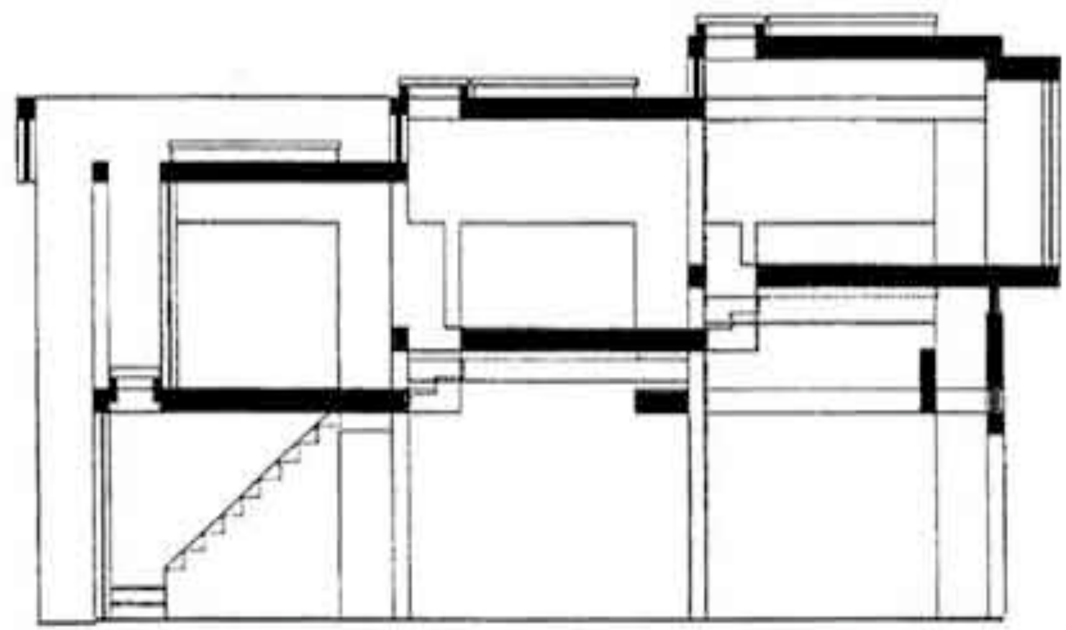
Overview of methodologies & technologies

METHODOLOGY / TECHNOLOGY	GOAL
Think aloud protocols	Characterize knowledge acquisition, reasoning processes, structure of knowledge
www	Support peer learning across the US/World & scale learning materials worldwide
Google Earth	Develop/implement rich visualizations beyond typical size and time scale
Logging (of students' interactions with simulations)	Characterize learning & adaptively tutor students in real time
Educational data mining	Analyze huge amounts of student log files

Domain of Architecture

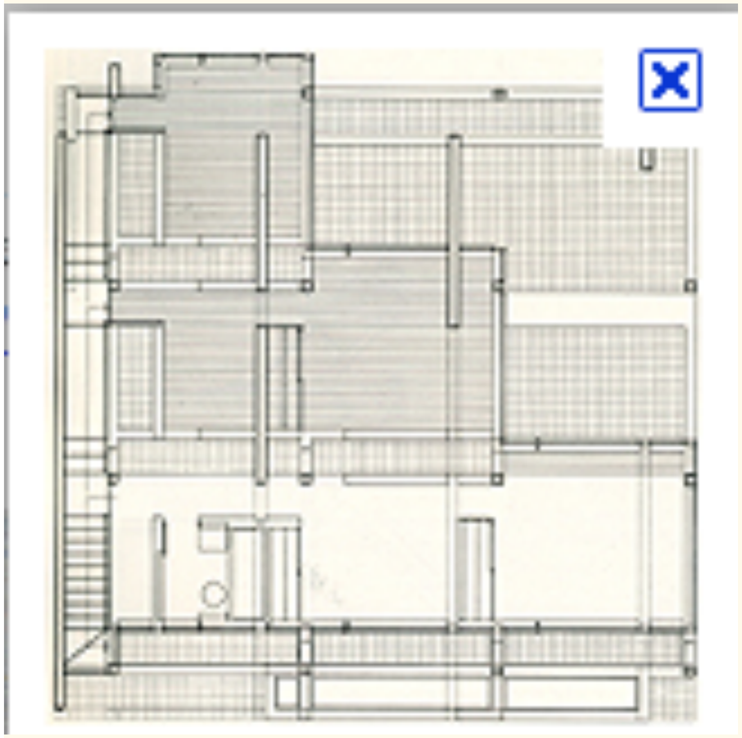
- Using think aloud and drawing protocols, I characterized e-n differences in
  - knowledge-acquisition processes while learning form plans,
  - inference making about 3-dimensions from plans (2-D) with edited plans.
- Task is analogous to reading topographical maps: hierarchy of line weights represents relative heights.





P. Eisenman, House II.

Experts were more systematic than novices in knowledge acquisition patterns.



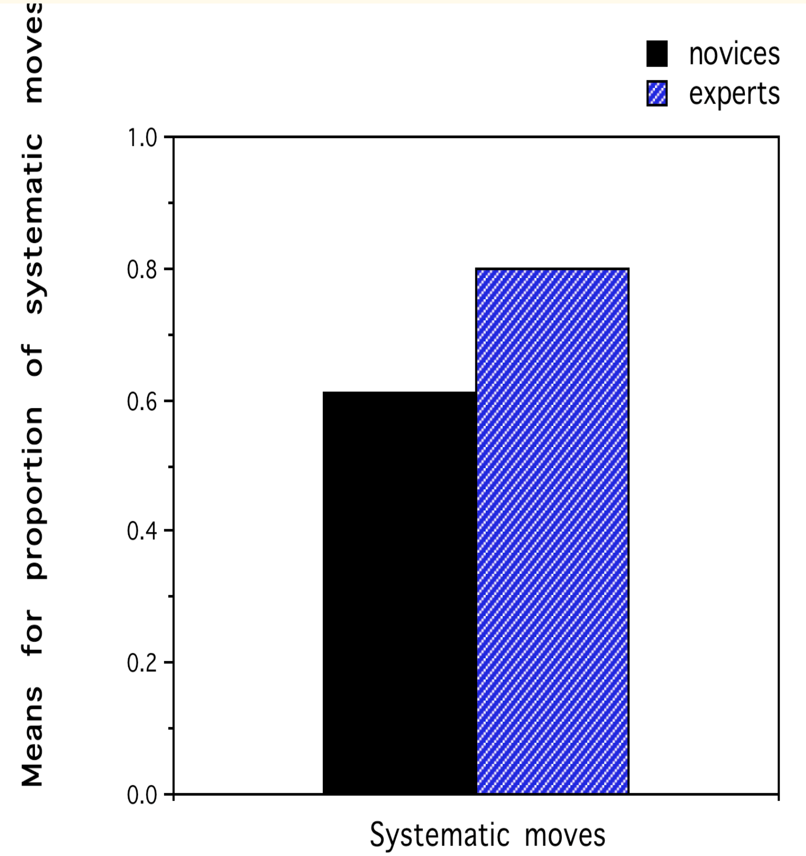


Figure 1: Expert-novice differences on systematic moves in think aloud protocols.

F=19.74, p.<.001

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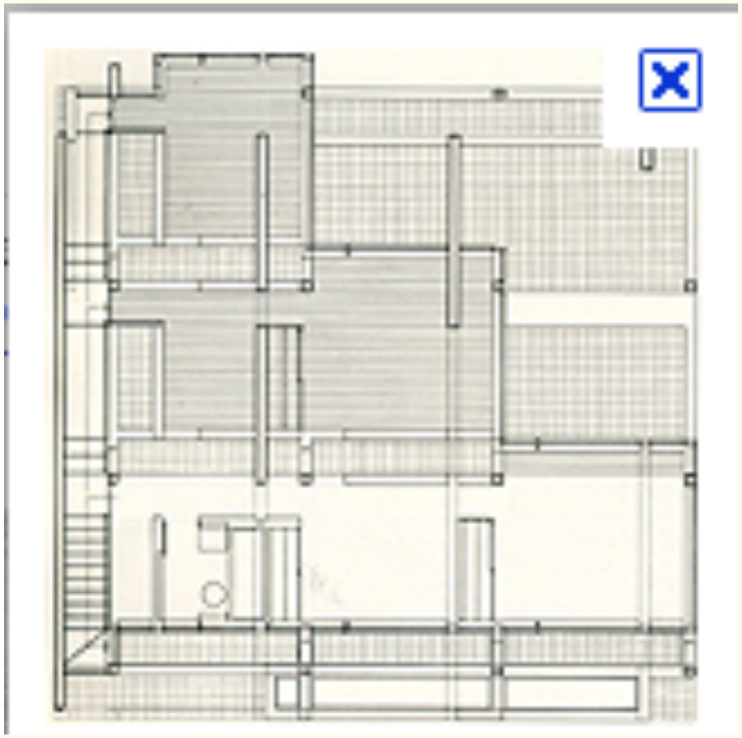
Experts outperformed novices on both 2-D and 3-D comprehension.



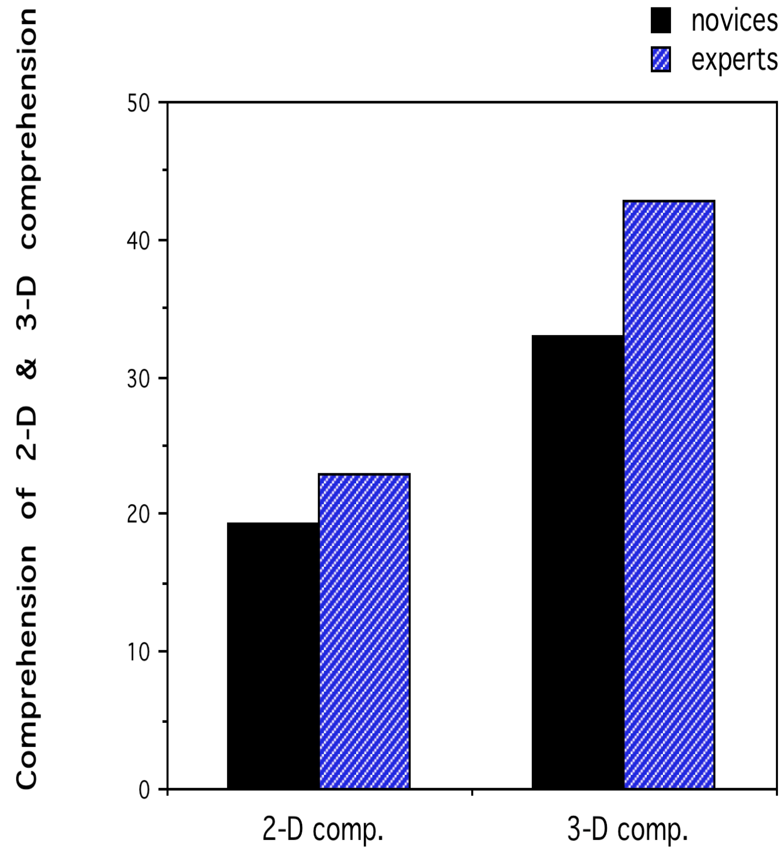
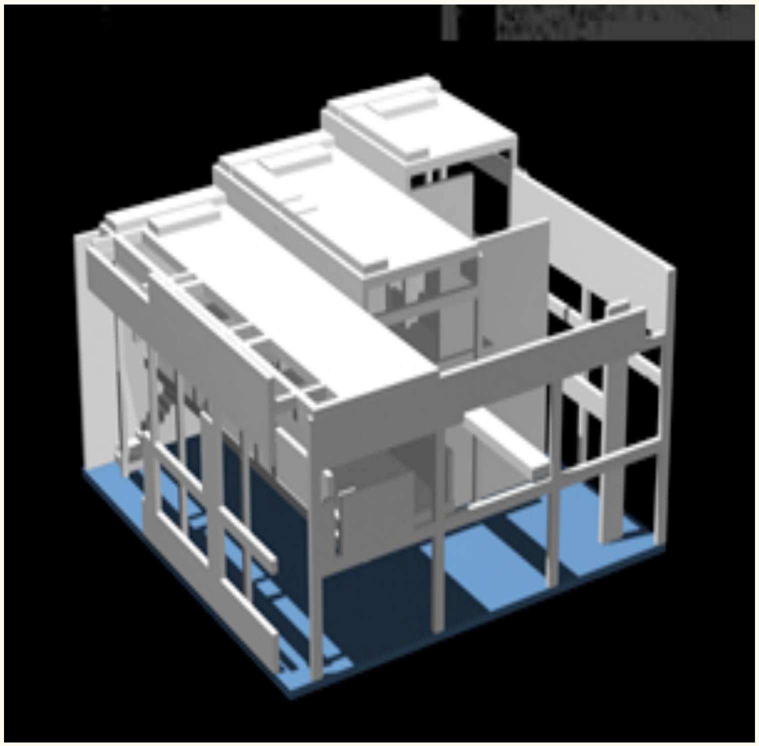


Figure 2: 2-dimensional & 3-dimensional comprehension, experts vs. novices.

2-D: $F = 21.27$, $p < .001$

3-D: $F = 37.18$, $p < .001$

Regarding Spatial Visualization skills



- **Spatial visualization skills ("ability to manipulate or transform spatial patterns") were statistically related:**
  - **3D search (in think aloud protocols)**
  - **2-D & 3-D comprehension**

Gobert, J. (1999). Expertise in the comprehension of architectural plans. In *Visual And Spatial Reasoning In Design '99, John S. Gero and B. Tversky (Eds.)*

Representations in Geology

- Like architecture, in geology 3-dimensional information is inferred from in 2-dimensional visualizations by differing line types and hierarchies of pen weights.

- Processes that occur over time (glaciation, mountain formation, etc.) must also be inferred from more subtle aspects of representations (as well as from prior knowledge).

Research on learning with visualizations in Plate Tectonics

Excellent domain to do this because:

- large use of visualizations
- important role of mental model building in understanding the hidden causal mechanisms, e.g., convection.

Task:

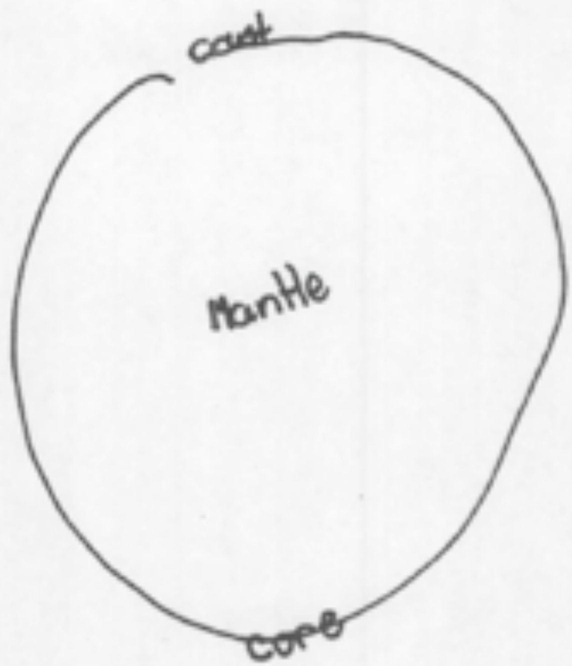
-- asked students to draw models of the inside of the earth & of the causal mechanisms responsible for plate tectonics.

(NSF-REC# 9806141 for next three studies).

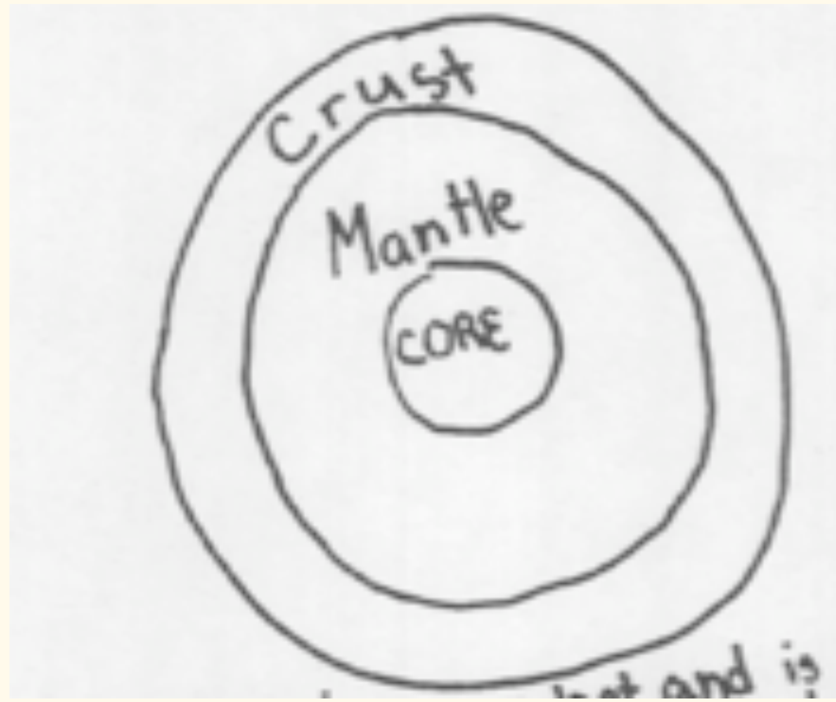
See also, Gobert, J. (2005b). In Journal of Geoscience Education.

Typical models of structure of earth of middle school students

Type 0= 10.6%, Type 1=89.4%



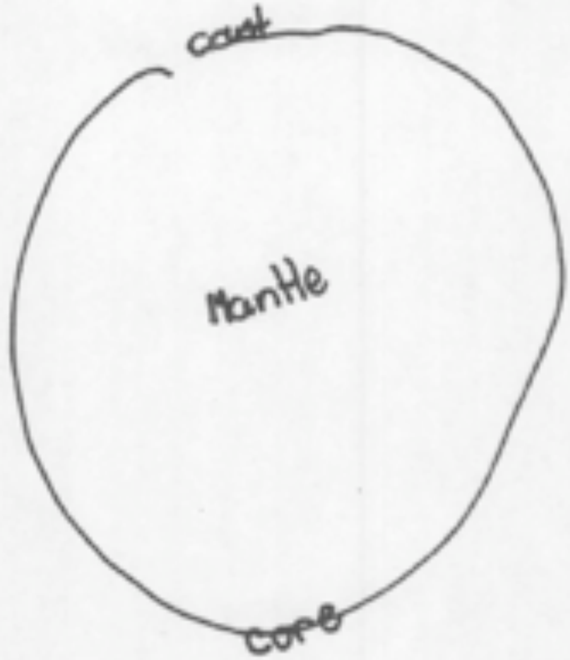
Type 0: Spatially Incorrect Model



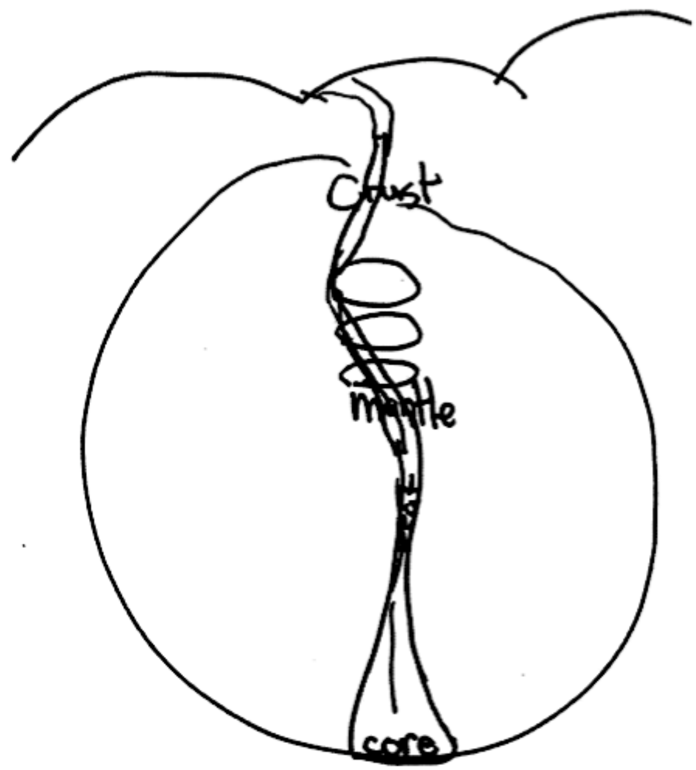
Type 1: Spatially Correct Model

Affordances (not!) of spatially incorrect model

Task: To depict processes inside the earth

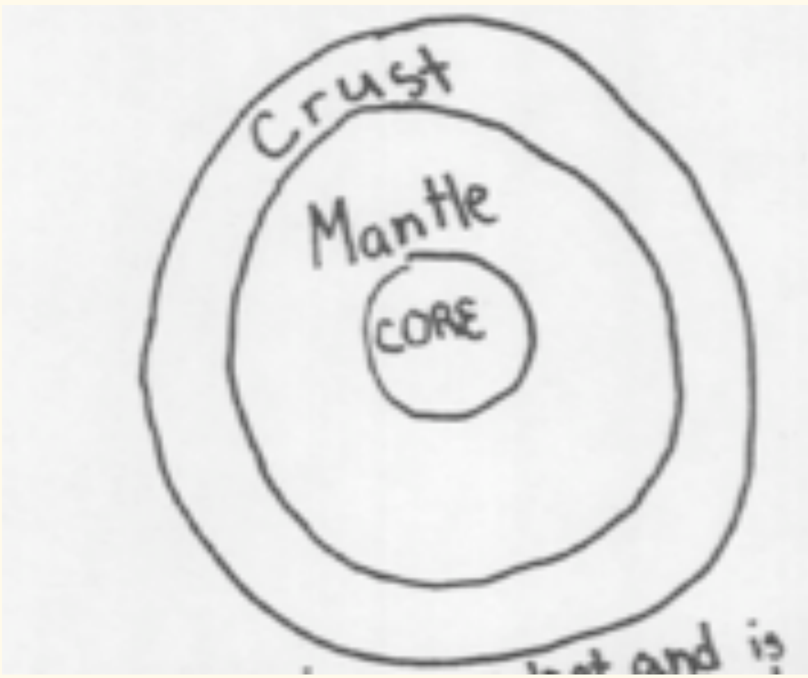


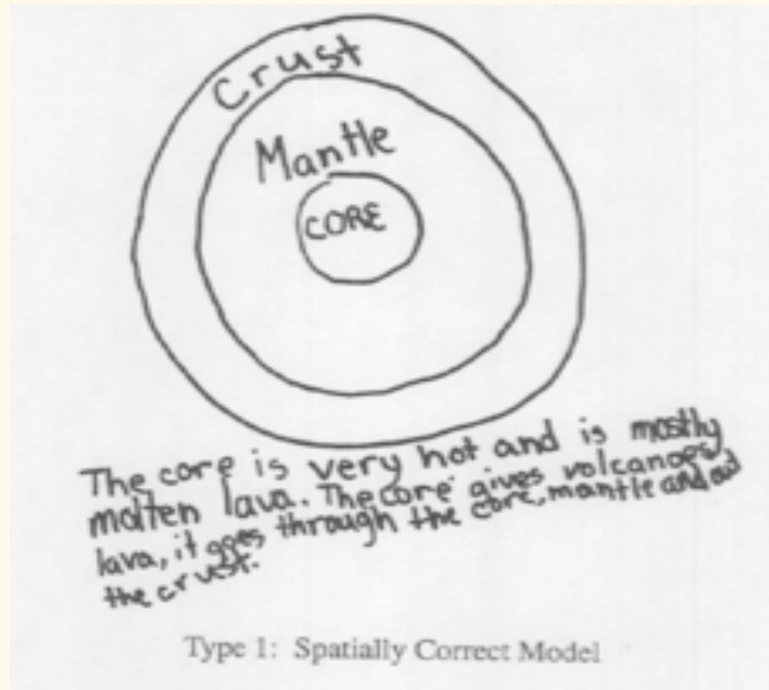
Type 0: Spatially Incorrect Model



Type 1a: local 'Heat' model

Affordances of spatially correct model





Type 1: Spatially Correct Model

E: “Why is the magma hot?”

S: “... the mantle is right near the core.”

From Gobert, J. (2000). *International Journal of Science Education, 22(9)*, 937-977.

Curriculum design study for Plate Tectonics to support students' model-based learning (NSF-REC# 9980600).

- 2,000 middle and high school students from CA and MA collaborated on-line in 2 X 2 peer groups about the differences in PT using WISE (Web-based Inquiry Science Environment; Linn & Hsi, 2000).

- The curriculum engaged students in many inquiry-oriented, model-based activities.

Gobert, J., & Pallant, A., (2004). Fostering students' epistemologies of models via authentic model-based tasks. *Journal of Science Education and Technology. Vol 13(1), 7-22.*

What's on your plate curriculum (mtv.concord.org)

- **Draw, in WISE, their own models of plate tectonics phenomena (mtn formation, volcanoes, or earthquakes).**

- **Participate in an on-line "field trip" to explore differences between the East and West coast in terms of earthquakes, volcanoes, mountains**
  - **- beginning with the most *salient* differences (earthquakes).**

- **Using visual representations, learn about location of earth's plates (to develop relationship between plate boundaries and plate tectonic phenomena).**

- **Using simulations, learn about causal mechanisms involved in plate tectonics, i.e., convection & subduction (scaffolded by reflection activities to integrate knowledge). ****

- **Learn to critically evaluate their peers' models which in turn serves to help them think critically about their own models.**

Cont'd

In doing these activities, students develop…

- Content knowledge (spatial, causal, dynamic, temporal)

- Epistemological understanding of the nature of scientific models.

- Inquiry skills for model-building and critiquing their peers' models. *

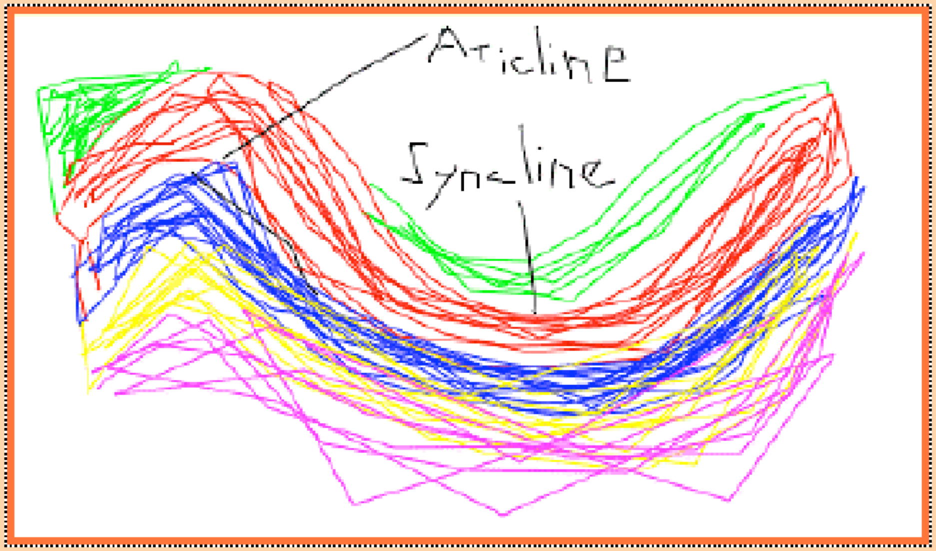
Findings:
Content and epistemological gains in all classes

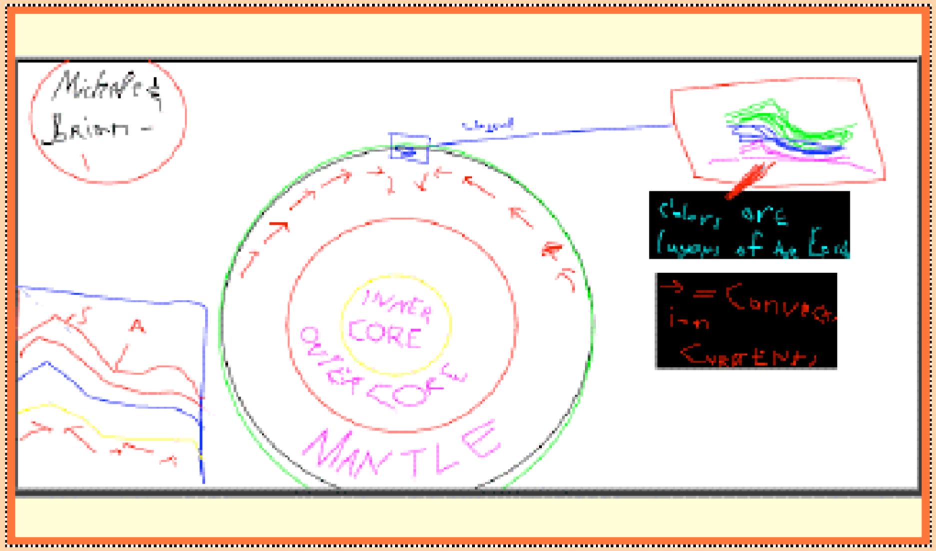
Significant model revisions as well…

EastWest (•) East ( ) W **PairID** 13 **Names** [redacted]

Complete ID SP13G13805_5Ea **Model Type** Mountain Building

Model Picture





My model is of the creation of a fold mountain; the Appalachians were made this way. The lowest part of the green surface is called the syncline. The syncline is a downward fold in the rock. The top of the green surface is the anticline; the upward fold in the rock. Folds vary in size, some more than others. Sometimes you need a magnifying glass to see a fold clearly, while others are as big as mountains. Our fold mountain has 2 synclines and one anticline. The Appalachian mountains are made up of lots of anticlines and synclines; maybe thousands. There are too many to count.

There are also three other types of boundaies; divergent, where new crust is formed; collision boundaries where two land masses collide; and transform boundaries where two land masses slide against each other. Geological features are subduction. Subduction swallows up the ground so Earth doesn't grow. At a depth of 190-430 meters the rocks begin to melt. Some of the melted rock, now lava, goes up to the surface of ocean and creates volanos. Most of it becomes a piece of the mantle, to reappear on the surface in a different boundary.

Original Model Score: 4 **Score Difference** 10 **Revised Model Score:** 14

Critique Score 1

Critique:

W13: We have evaluated your model.The parts that helped us to understand the process you were modeling were the labels that you had("anticline and syncline").We will also make the following suggestions that will help us better to understand your model.Label the colored part of you model.Put all the important labels on your model(enough for a person who hasn't learned this before to get the idea).

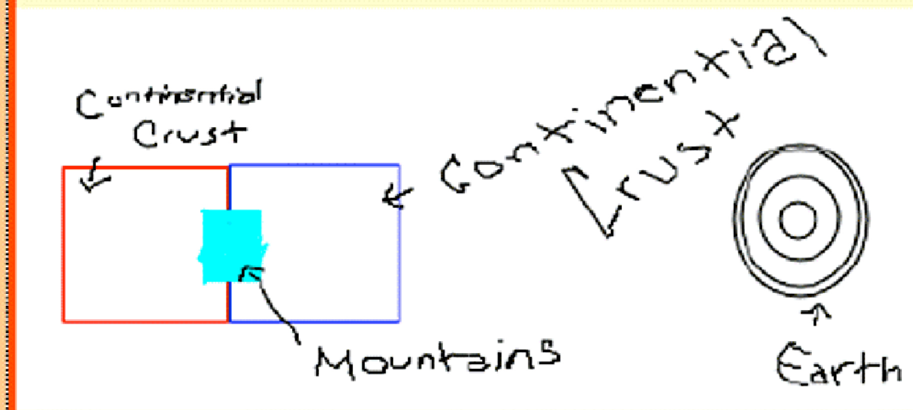
Comments on example 1….

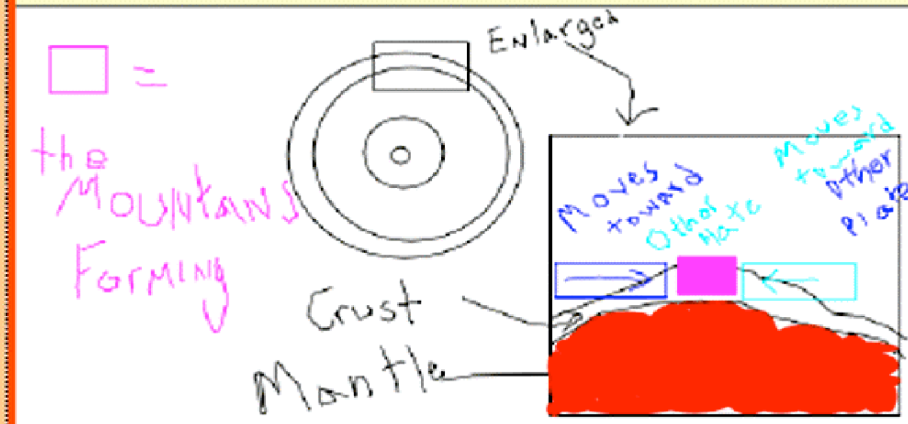
- in model t1, “local” model, focused on crustal layer, no causal mechanisms
- in model t2, revised model is more detailed and shows a cut away section to reveal convection currents (causal mechanism).
- model is improved in both content and communication.

EastWest ◉ East ○ W **PairID** 3 **Names**

CompleteID SP3G13824_5East **Model Type** Mountain Building

Model Picture





My model is of .....(name which geologic process it shows). the App. Mts. forming. Write a detailed explanation of what is happening inside Earth and on its surface. Two c.crusts are colliding together to form the App. Mts. The red box and the blue boxes are the continential crusts that are colliding together and the baby blue box is the App. Mts.forming.

My new model is of.....two contineta l plates and mountains. Here is my revised explanation.....The two Contineta l plates are colliding and are forming a mountain range. The blue and the cyan are the plates colliding and the magenta is the mountains forming the red is the mantle which helps the plates move.

Original Model Score: 11

Score Difference 4

Revised Model Score: 15

3 **Critique Score**

Critique:

W3: We have evaluated your modle. The parts that helpped us understand what you were modeling was the expelenation. You could make your model more than some squares. Show the direction of movement of the plates. Instead of a birds eye view, givea cross section and show more detail.

Comments on Example 2….

• in model t1, no causal mechanisms
• peer's critique asks for arrows to show direction of movement of plates, also they ask for a cross-section view.
• model t2, provides cross section showing plate movement & direction, magma layer is also added.

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Technology to trace students' learning with models
(mac.concord.org)

Principal & Co-Principal Investigators

Paul Horwitz, Concord Consortium, PI
Janice Gobert, formerly of Concord Consortium, Co-PI
Robert Tinker, Concord Consortium, Co-PI
Uri Wilensky, Northwestern University, Co-PI

The Modeling Across the Curriculum project addresses:

- **how technology can support student learning & assessment with visualizations and simulations**
- **how technology allows for scalability (over 400 schools in 31 countries).**

mac.concord.org; IERI #0115699

In response to IERI rpf, we set the following goals…

We developed content in the form of microworlds:

- **Newtonian Mechanics (Dynamica)**
- **Genetics (BioLogica)**
- **Gas Laws (Connected Chemistry, developed by Wilensky et al)**

We developed technology, i.e., Pedagogica, a powerful infrastructure:

- **Delivers curricular materials**
- **Logs learners' interactions with models**
  -- provides performance assessment data for both researchers and teachers.

We measured:

- **HOW students are learning with models across trials, tasks, and domains using log files.**

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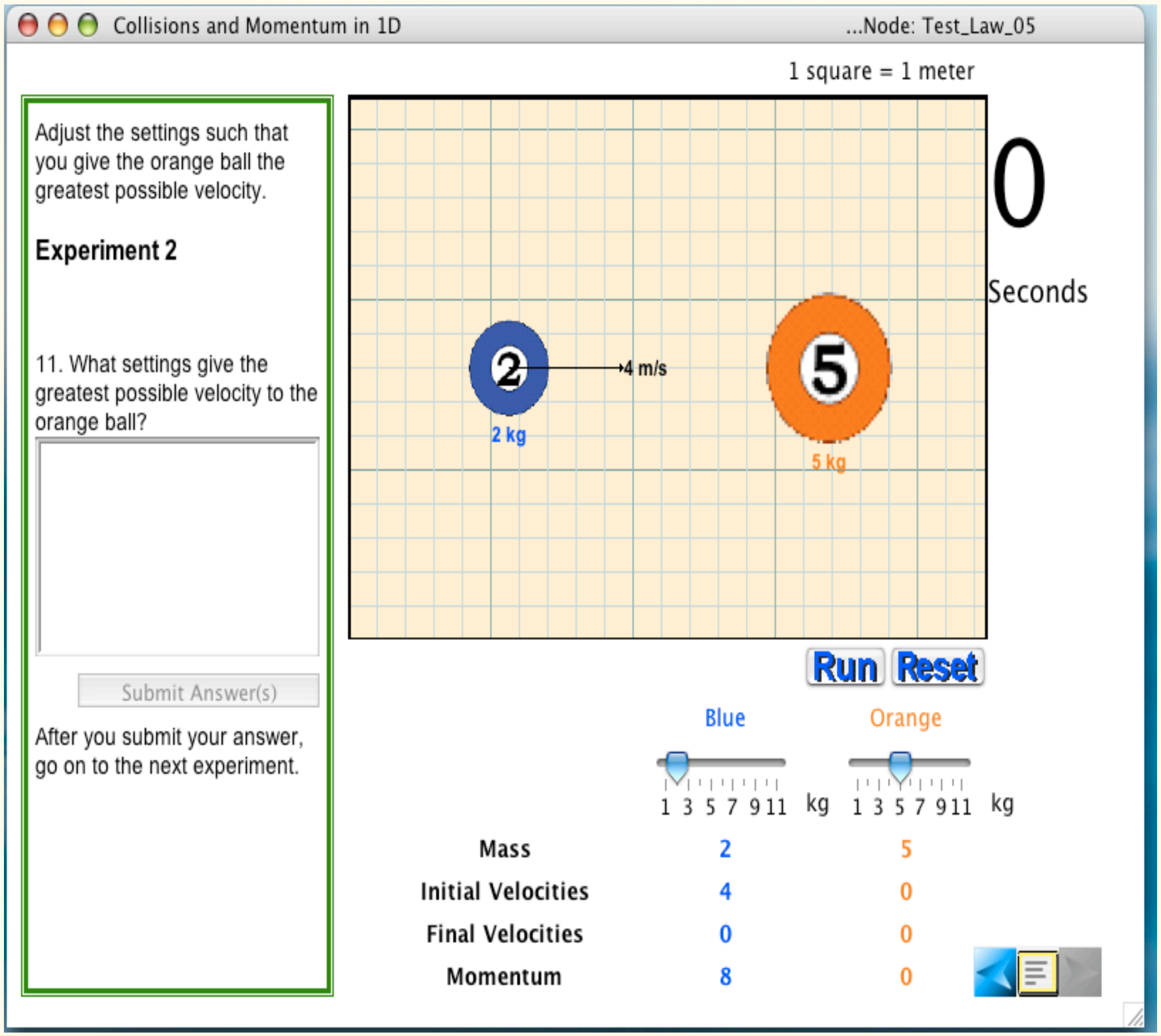
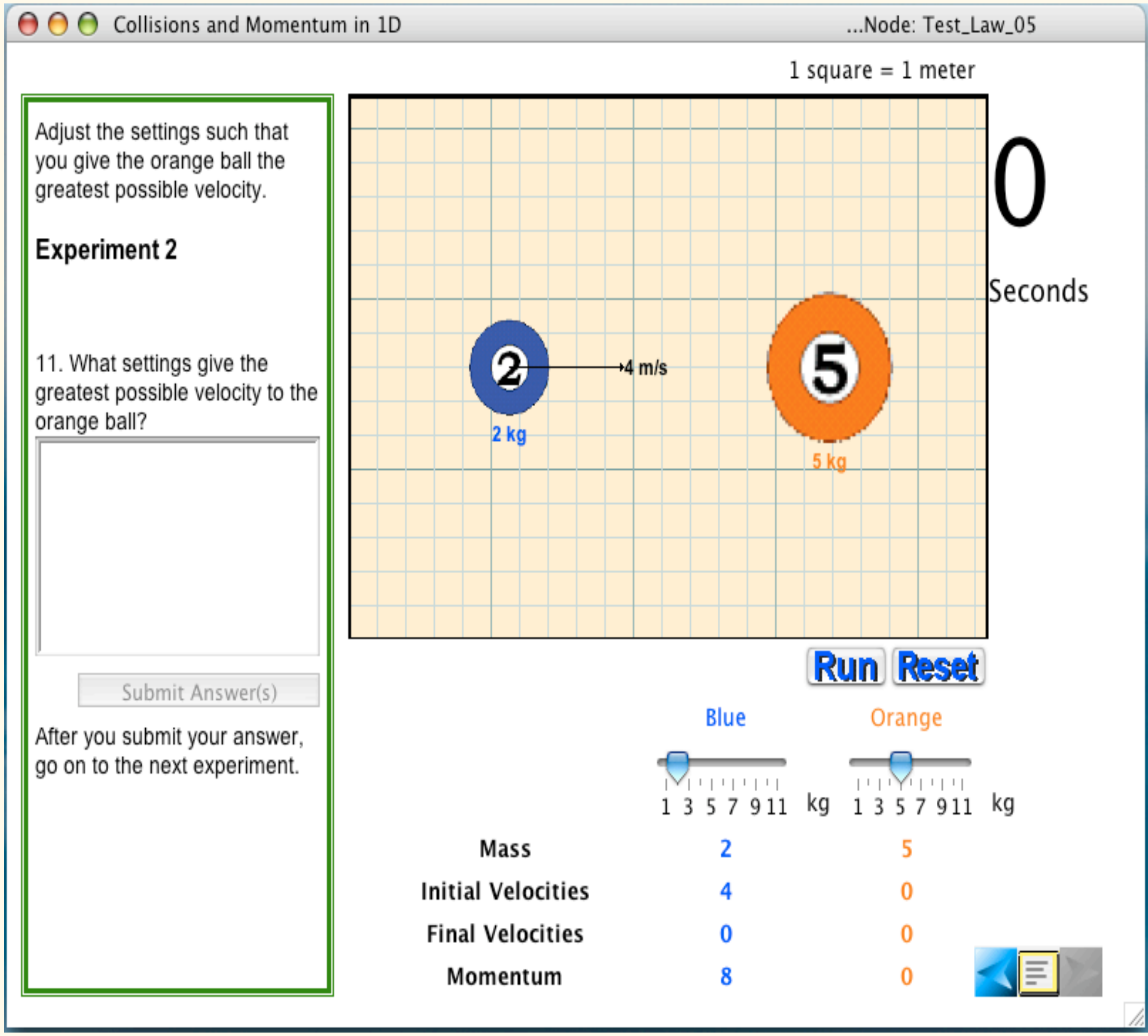
Affordances of Students' Experimentation with Microworlds: A Haphazard Strategy



Student 12116 made 15 trials:

Blue Ball	Orange ball
11.0	11.0
11.0	1.0
11.0	3.0
11.0	4.0
1.0	1.0
1.0	11.0
8.0	7.0
11.0	2.0
11.0	11.0
11.0	1.0
11.0	5.0
3.0	5.0
1.0	5.0
1.0	8.0
11.0	1.0

Student's Systematic Strategy, e.g., vary one ball at a time (good strategy in the absence of prior knowledge).



Student 18115 had a plan:

Blue Ball	Orange ball
11.0	11.0
5.0	11.0
10.0	11.0
11.0	1.0

Steps for analysis of log data*

An iterative process of

- **task analysis of inquiry tasks (Ericsson & Simon,1980)**
- **development of rubrics**
- **hand scoring logs**
- **writing algorithms for auto-scoring logs**
- **validating auto-scoring algorithms**
- **validation of summary/concise reports for export to 3rd party statistics programs**

Buckley, B., Gobert, J. & Horwitz, P. (2006). Using Log files to Track Students' Model-based Inquiry. In the *Proceedings of the Seventh International Conference of the Learning Sciences (ICLS), Mawah: NJ: Erlbaum, pp.57-63.*

What is auto-logged on task 3

Auto-scoring of % trials in which students:

- **Varied one ball (systematic, CVS used)**
- **Repeated trials (haphazard)**
- **Equal & extreme pairs (systematic)**
- **Closer to & further from the goal**
- **Goals flips.**

Why do we care?

Because we can use logs to predict learning:

i.e., Significant correlations found between gain score and

- **total time on task (r= 0.23)**
- **reading time (r= 0.20)**
- **# trials (r= 0.20)**
- **% equal pairs (r= 0.23)**

Performance Assessments in Dynamica

- Model-based learning, e.g., systematicity is auto-scorable in students' actions.
- Well-suited to assessing students' systematicity because of the well-defined domain, and numerical form of data.
- There is a relationship between inquiry strategies and post-test gain scores; e.g., # trials, and using the equal pairs strategy.

Current work: Science Assistments

Janice Gobert, PI

Other Co-Investigators

Dr. Neil Heffernan - Computer Science
Dr. Ryan Baker, Social Sciences
Dr. Carolina Ruiz, Computer Science
Dr. Joe Beck, Computer Science
Dr. Ken Koedinger, HCI, Carnegie-Mellon

Graduate Students & Staff:

Arnon Hershkovitz, Ph.D, Post-Doctoral Researcher
Michael Sao Pedro, Ph.D. Student, Computer Science
Juelaila Raziuddin, Ph.D. Student, LS&T
Ermal Toto, Ph.D. Student, LS&T/Software Engineer
Orlando Montalvo, Ph.D. Student, LS&T/Software Engineer
Adam Nakama, M.Sc. Student, LS&T
Matt Bachmann, M.Sc. Student, Computer Science
Mike Wixon, M.Sc. Student, LS&T
Cameron Betts, M.Sc. Student, LS&T

Project Overview

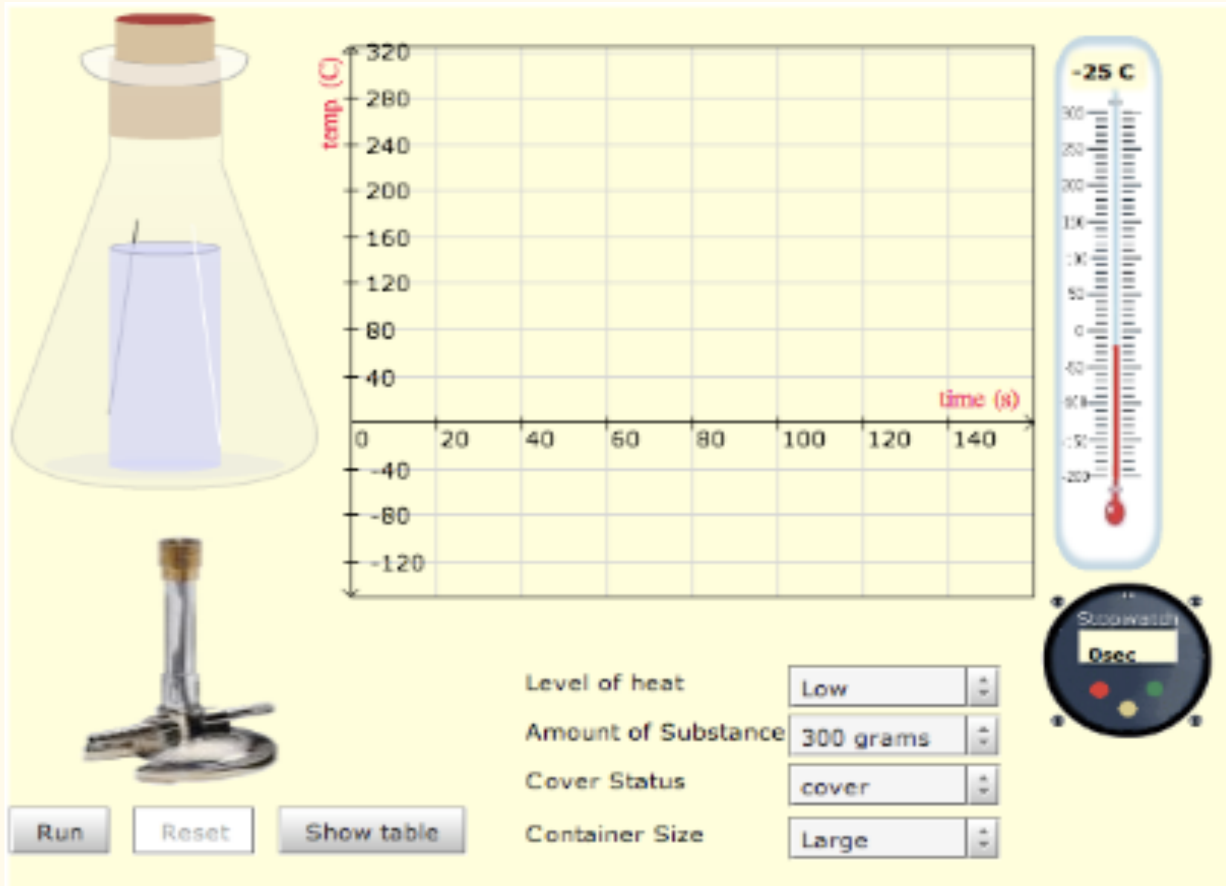
- Science Assistments is a technology-based environment for assessing and assisting middle school students on inquiry *.
- Our activities are based on *guided inquiry* & *experimentation* with microworlds.
- We are developing auto-tutoring of students' inquiry.

Hello! You are going to be a scientist today and conduct experiments in a virtual laboratory!

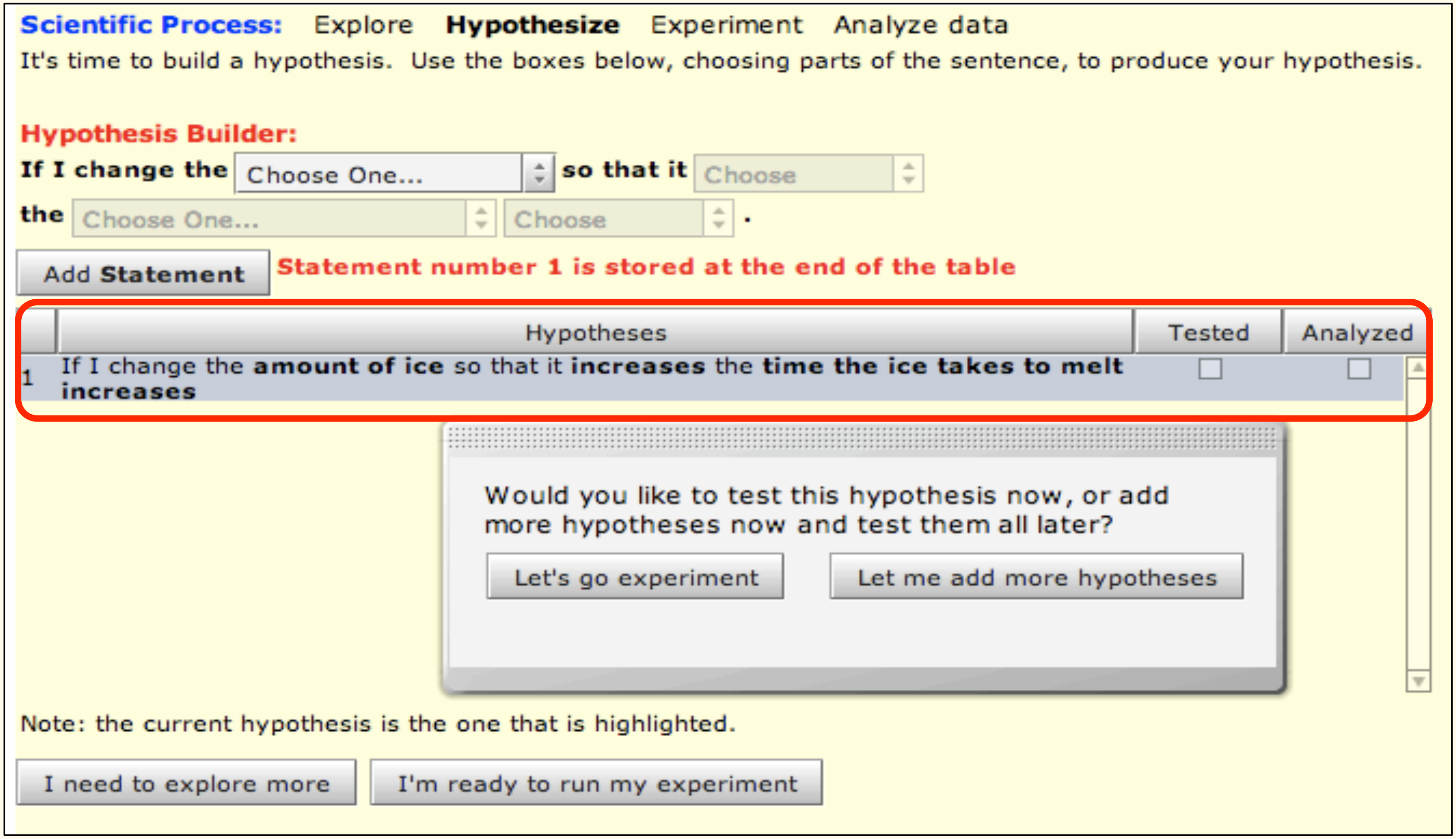
Students *learn* and are *assessed* while they do inquiry with microworlds

- **With microworlds, students:**
  - ***develop a hypothesis,***
  - ***design & conduct an experiment***
  - ***analyze data & warrant their claims, and***
  - ***communicate findings (NSES, 1996).***
- **Because we log all students' actions, we can tutor students in real time.**

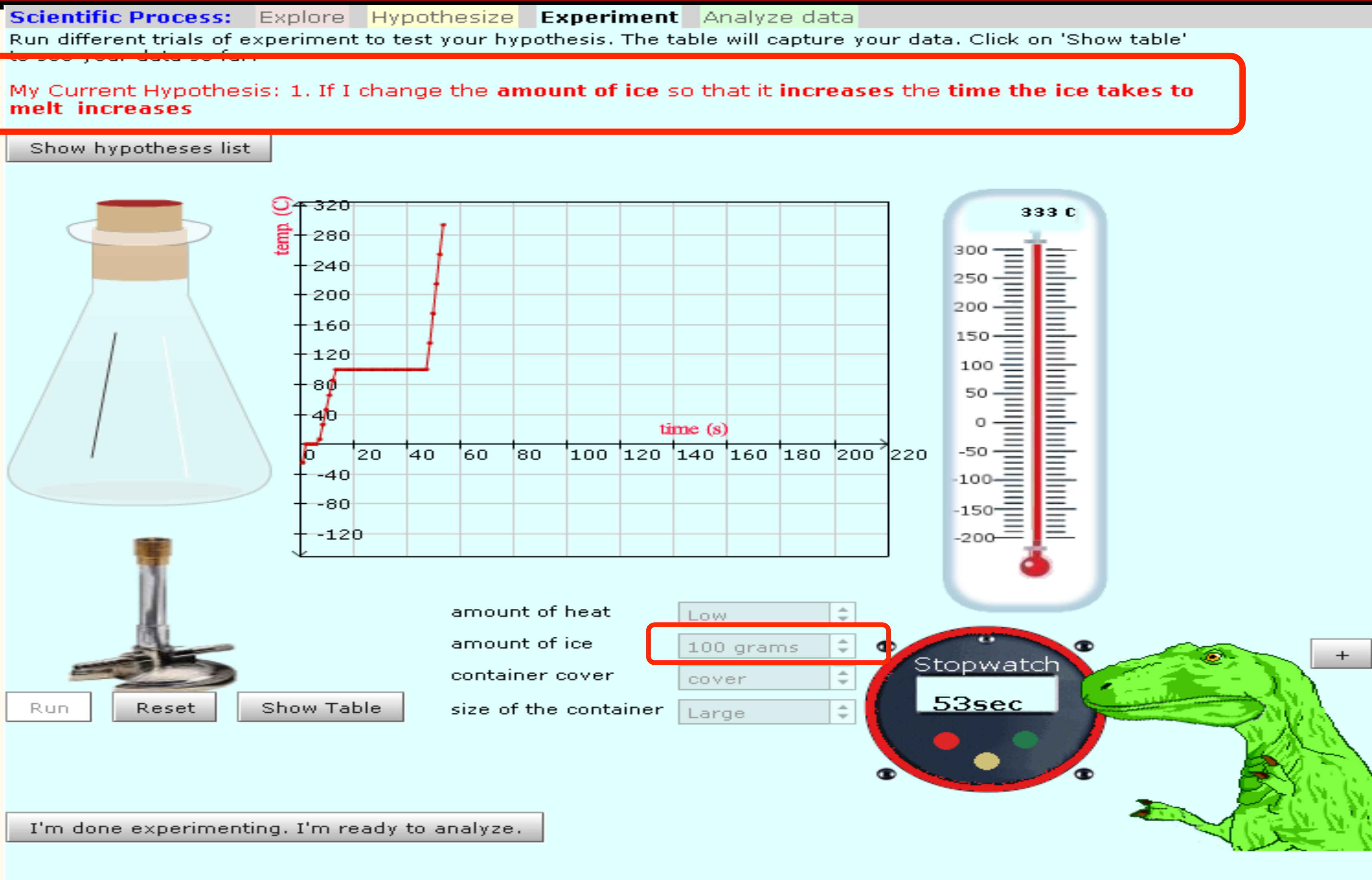
Example of our State change microworld…



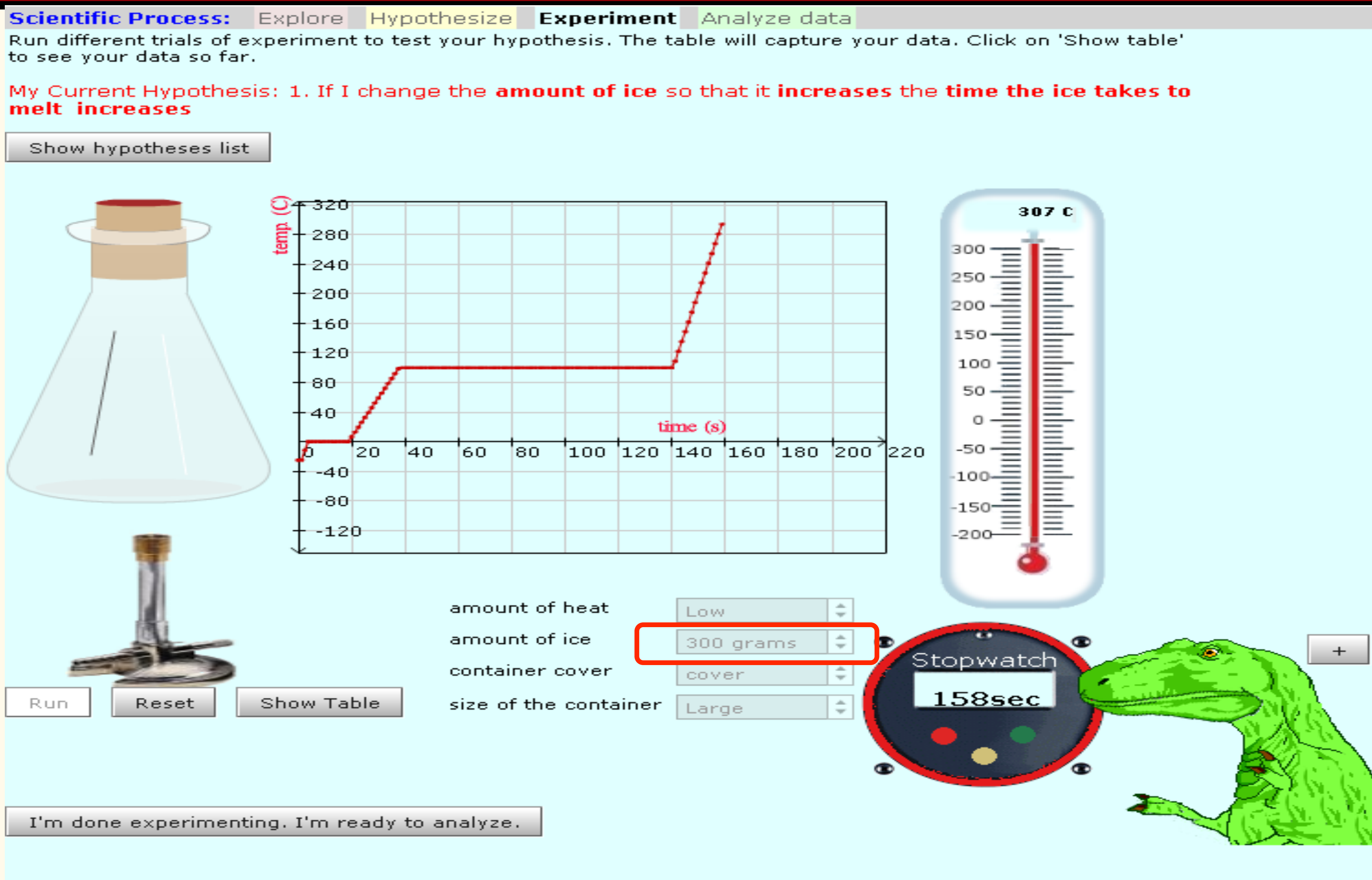
Student makes a hypothesis



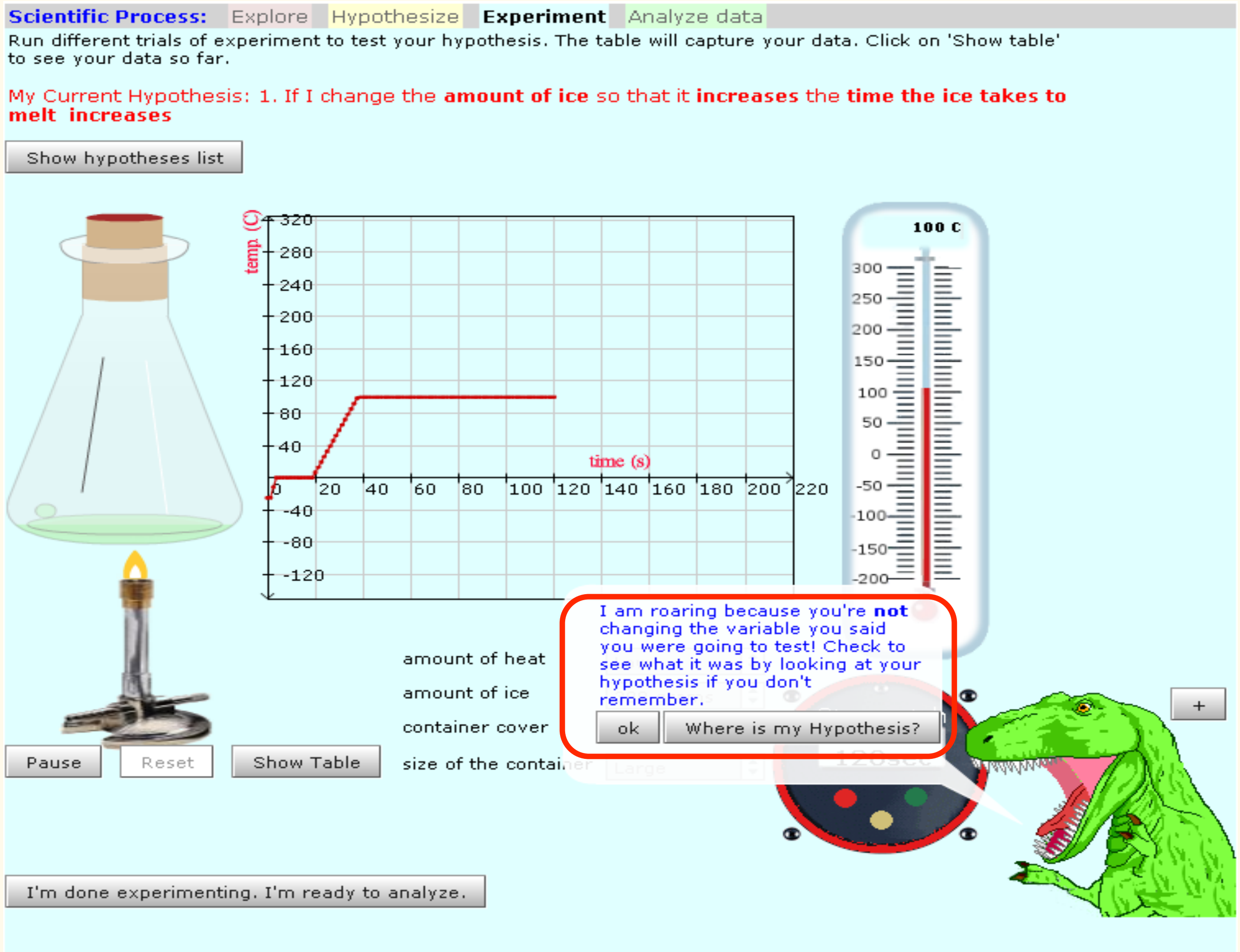
Student tests hypothesis: Trial 1



Student tests hypothesis: Trial 2



If student is not testing their hypothesis …



3 levels of hints

Student interprets data from table

		Independent Variables				Dependent Variables			
Trial Number	Hypothesis Number	Has Cover	Container Size	Heat Level	Liquid Amount	Melting Temp(°C)	Boiling Temp(°C)	Time(sec) Melting	Time(sec) Boiling
1	1	true	Large	Low	100 grams	0	100	5	35
2	1	true	Large	Low	300 grams	0	100	16.25	102.5

Student warrants claim with their data

Scientific Process: Explore | Hypothesize | Experiment | **Analyze data**

Now it's time to look at the table of data and analyze.

My Current Hypothesis: 1. If I change the **amount of ice** so that it **increases** the **time the ice takes to melt increases**

Show hypotheses list

		Independent Variables				Dependent Variables			
Trial Number	Hypothesis Number	Has Cover	Container Size	Heat Level	Liquid Amount	Melting Temp(°C)	Boiling Temp(°C)	Time(sec) Melting	Time(sec) Boiling
1	1	true	Large	Low	100 grams	0	100	5	35
2	1	true	Large	Low	300 grams	0	100	16.25	102.5

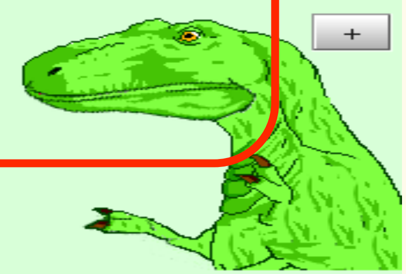
Data Interpretation:

When I changed the Choose One... **so that it** Choose **the** Choose One... Choose **. I am basing this on: Data from trial:** choose a trial **compared to data from trial:** choose a trial **. This statement** does support **my hypothesis.**

Add Statement

	Interpretations
1	1:When I changed the amount of ice so that it increased the time the ice took to mel increased. I am basing this on data from trial 1 compared to data from trial 2. This statement does support my hypothesis

+



Go back. I need more data. | I'm done. Let's do another hypothesis. | I'm all done

If student interprets data incorrectly …

Scientific Process: Explore | Hypothesize | Experiment | **Analyze data**

Now it's time to look at the table of data and analyze.

My Current Hypothesis: 1. If I change the **amount of ice** so that it **increases** the **time the ice takes to melt increases**

Show hypotheses list

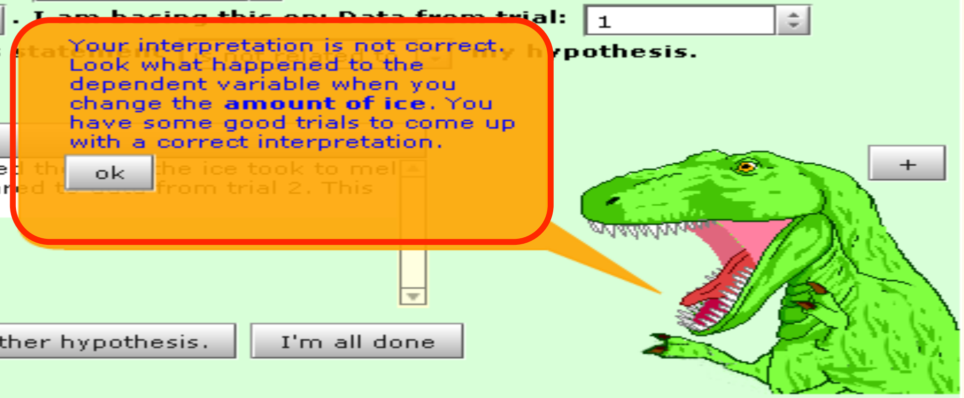
		Independent Variables				Dependent Variables			
Trial Number	Hypothesis Number	Has Cover	Container Size	Heat Level	Liquid Amount	Melting Temp(°C)	Boiling Temp(°C)	Time(sec) Melting	Time(sec) Boiling
1	1	true	Large	Low	100 grams	0	100	5	35
2	1	true	Large	Low	300 grams	0	100	16.25	102.5

Data Interpretation:

When I changed the amount of ice **so that it** decreased **the** melting point decreased. **I am basing this on: Data from trial:** 1 **compared to data from trial:** 2. **This** ... **my hypothesis.**

Add Statement

	Interpretations
1	1:When I changed the amount of ice so that it increased the ... the ice took to melt increased. I am basing this on data from trial 1 compared to data from trial 2. This statement does support my hypothesis



Go back. I need more data. | I'm done. Let's do another hypothesis. | I'm all done

3 levels of hints

Communicate findings

Pretend you are explaining your conclusions about the effects of the **amount of substance** on each of the dependent variables to a friend who did not do the experiment. Discuss how you conducted this experiment and how you came to your conclusions. Be as specific as possible (example: mention the independent variable and its effects on each of the dependent variables).

…Students' skill level for content understanding and inquiry skills are generated

For Inquiry skills:

Hypothesizing

- IV, DV

Conduct trials

- Testing the IV/ their hypothesis
- Using CVS

Interpret Data

- Correct claims
- Warranted claims

Communicate Findings

To code communication skills (under development)

- To code open responses to react in real time:
  - "Nonsense" detector
  - "Too short response" detector
  - "Not correct terms"

Educational Data Mining to auto-analyze log files

- Once logs are labeled, use EDM to determine what fine-grained logged features correspond to specific inquiry skills.
- Build detectors over feature sets, i.e., aggregates of logged actions.
- Validate detectors (see Sao Pedro et al, Montalvo et al, 2010 on our website).

Using Detectors to Predict Performance

Using our detectors as a basis for assessing skills, we can:

(1) Predict skill proficiency before a student starts a new activity

(2) Test the relationship between a skill honed in our learning environment and other transfer measures of inquiry

See papers on our website (Sao Pedro et al, Montalvo et al) for techniques and results.

Research like this has important implications for…

1) Learning Sciences

- provides a bird's eye view into the "black box" regarding students' learning processes with greater validity than previous measures

2) Intelligent Tutoring Systems

- is an essential component of ITS which can fade scaffolding as a student's skill level increases.

3) Science Education

- is critical for formative assessments for teachers
- richer assessments of science learning

4) Scalability

- our materials can reach any learner on the web.

Implications for some future research for you

- GE to support students' understanding of spatial, dynamic, and temporal processes.
  - Fine tune items and assessment to capture different facets of knowledge.
- GE to develop in students a sense of *how we know what we know about geologic processes*
  - Important to deep learning (& scientific literacy)
- In terms of assessment, you can relate students' knowledge acquisition processes to their learning outcomes by *logging* students' actions.

Question to ponder

- **What are the prerequisite skills needed to leverage from what Google Earth has to offer for learners?**
  - **- variance of these in students**
  - **- can get an empirical handle on these to better measure learning.**

Thank you!

Jgobert@wpi.edu

www.scienceassistments.org