Why Should We Care?

Practically every general science book and every State or National Standards document has something in it about the nature of science or, lamentably, the "scientific method." Yet the curriculum attached to this learning goal often consists of history boxes describing how Gregor Mendel (for example) studied peas, and a sanitized picture of how scientists observe, create hypotheses, experiment, dispassionately toss bad hypotheses, and gradually build up theories and/or laws.

While there is a kernel of truth in that description, it misses a lot of the process—collaboration, for example—and denies the passion: both the devotion to our own (brilliant) ideas, and the joy of the *aha!*, of figuring out how things work. Let's figure out a way to show students what really goes on—because the truth is far more interesting.

Here's a quote that approaches this from a different direction:

> "When people know how scientists go about their work and reach scientific conclusions, and what the limitations of such conclusions are, they are more likely to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically… The myths and stereotypes that young people have about science are not dispelled when science teaching focuses narrowly on the laws, concepts, and theories of science. Hence, *the study of science as a way of knowing needs to be made explicit in the curriculum*."

(AAAS, *Benchmarks for Science Literacy*, p. 3, our emphasis)

The Big Idea

The class becomes a community of scientists investigating a phenomenon or pattern. We mean this very broadly: students will participate in the development of an entire discipline; they will uncover a body of knowledge. They will see hypotheses come and go, supported or shattered by experiments they design; their theories will emerge from accumulated research; and they will know first-hand that science is not a solitary enterprise, but depends on interaction and communication.

Ideally, a student's experiences in the simulation can become a touchstone to which the instructor can refer throughout any course.

Scarce Resources

Experiments cost money. You run out quickly. (This is part of what we mean by giving students a greater appreciation for the practice of science…)

In fact, the scenarios are designed so that it would be very hard for any group to come to deep and meaningful conclusions on their own. They must choose their experiments carefully. They have to share data. And they have to stand on the shoulders of giants, or at least those of their classmates.

Sharing happens through the mechanism of the *journal*.

The Journal

The journal is the most important part of the simulation. Originally, it was simply a way for students to record their thinking, but it quickly became the communication center of the activity.

Here's how it works in the current prototype:

If your group has some idea they want to publicize, they should write a (short) article and submit it to the journal.

If the journal editor (a teacher at first, but later, perhaps a committee of students) approves of the paper, it is published. A paper might be rejected or sent back for changes.

Published papers appear in the online journal for all to read.

A paper should reference any published papers it draws on and any data that support assertions made in the paper.

If you have read a paper that refers to data, you have access to that data. This means that (among other things) if you have run out of money, you can still write papers that draw conclusions from others' data, or make theoretical predictions inspired by other data or journal articles.

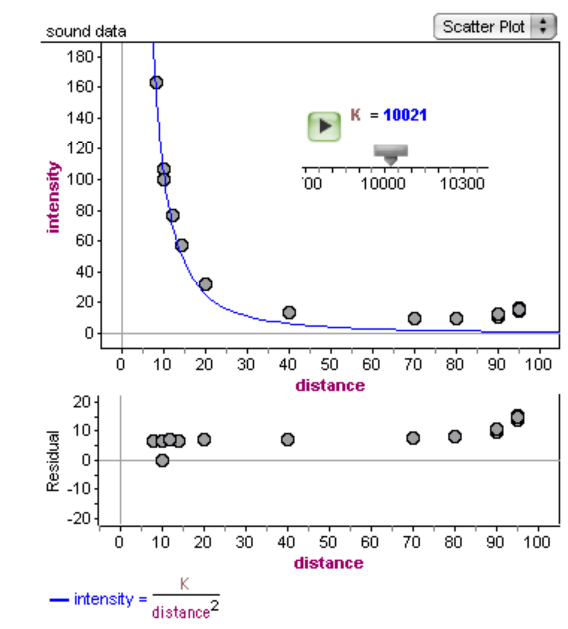
Do students get anything from writing journal articles? *No.* But they seem to want to do it anyway.

Getting More Money

When a group runs out of money, we first ask if they have read the journal. That usually holds them for a while. But eventually, they need more funds. When we have had enough class time, we have encouraged students to make grant proposals.

There is not yet any on-line mechanism for submitting proposals, and it's not clear if it would be a good idea.

In one field test, it worked like this: a group makes a proposal verbally to the instructor. They must specify how much money they want, what they want it for, and why. We want to know generally what experiments the group plans to run and what they hope to learn from the results. We have encouraged instructors to be stingy and picky (i.e., realistic).



Above: sample data from the sound scenario, undergoing analysis in Fathom. The residual plot suggests that we're off by a constant term…could this be ambient sound? And what's going on after distance = 90? Is that real or is it noise?

In this scenario, even though students may not be constructing "big" hypotheses or theories, they have to deal with real data problems such as calibration.

Simulating the Nature of Science

Scenarios

The Four-Color Universe

In this scenario, you are trying to learn about the universe (no small order). In this case, the universe is a 12-by-12 array of cells, each of which contains one of four colors (see the vignette).

Experiments (or observations, if you wish) tell you only the *distribution* of colors within 3x3 or 2x2 sub-arrays of the whole universe.

You can try this by logging in and choosing **AAPT 4-color Universe**. For a look into what high-school students do with this, log into **DVH2.colors** and join any old team. Read the journal to see what they did. This author (Erickson) wrote one paper at the beginning of the period while demonstrating how to do experiments and write papers.

The journal is in reverse chronological order. You will see how the classroom teacher (who was also journal editor) sometimes accepted papers that would ordinarily be rejected as duplicates—but he relaxed standards to help students get going.

Puzzle Versus Science

One difficulty with this scenario is that some students get enmeshed in the puzzle-and-logic aspects of the universe and experiments. It seems that they are—reasonably—trying to learn "the pattern of the universe" instead of learning what they can "*about* the pattern of the universe."

Both approaches are important, of course; but to promote the second as a possibility, we often begin a session showing students how to get one observational result (for example, a 3x3 that contains 3 blues, 2 reds, and 4 greens). Then we ask, given only that information, "what conjecture can you make about the universe that is supported by data?"

They might say, "There's no orange." At this point, we say that this is worthy of publication, and show them how to write a paper and reference the relevant data. Since this conjecture is likely to be false, this also sets up a lesson in the debriefing.

Sound

This scenario began its life as a guess-my-function game. In order to give it more context, we reworked it to be about sound intensity. A high-school teacher requested the context because the classes were going to do a sound-intensity lab in the next few weeks. This, in this scenario, you are trying to learn about how sound intensity depends on distance. At least that's what it seems like at first.

You use your money to buy time at the National Sound Laboratory, where you have absurdly simple equipment: an amplifier, a loudspeaker, and a microphone that will tell you sound intensity.

You can set the volume knob on the amplifier, and the distance between the loudspeaker and the microphone.

You can try this one by logging in and choosing the **AAPT Sound Scenario**.

Here you get quantitative data, of course, and we expect it to fall off inversely with the square of the distance. It does, but there are other issues that arise.

Students can enter data by hand into data analysis tools, or automatically if the tool supports it (e.g., Fathom and TI Interactive).

This is not so much about Science Writ Large as it is about dealing with data in a realistic experimental situation—with all of the physical equipment problems removed. It is surprisingly hard for experienced students to cope with completely.

Part of the work of this project is to design more scenarios and test them for balance, workability, ease of use, etc. In our "Phase I" period, intended only as a feasibility study, we created the four-color universe, the sound scenario, and two more (not pre-set-up here at AAPT).

Alien Blood

This is a life-science oriented scenario in which you have alien creatures in the lab whose blood you can sample. Each sample has a number of red cells and a number of blue cells.

The key thing here is that the proportions of cells change with time and with the creature's activity.

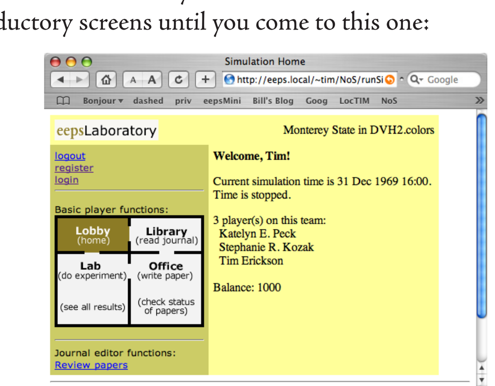
Custom Scenario: Using Real Data

In this scenario, the instructor, perhaps in collaboration with the class, decides what variables will be in the database. Then, instead of simulating the data, groups input values for the observations, for example, as a result of their own work.

While we have not tested this in class, we see it as an intriguing way to share data and to implement what we call "nested" labs, in which each group works with a slightly different setup (e.g., ramps at different angles). Each group's work in the lab may result in one number (the acceleration, say) that becomes a single data point in the *class* data set.

Vignette: A Four-Color Universe

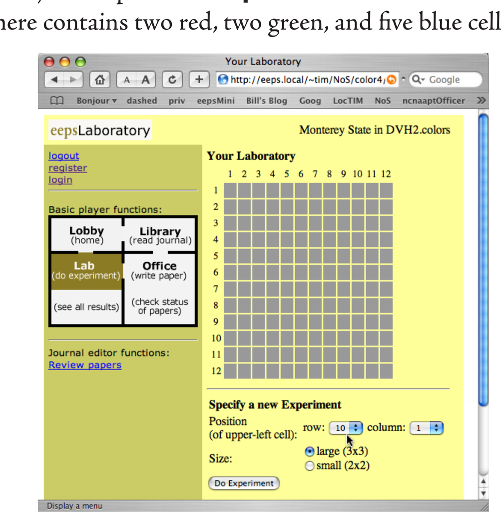
Your teacher tells you that your group is going to be a team of scientists at a university. Your team chooses a name (you pick "Monterey State") and uses your web browser to go to a particular URL. There you enter the name and click through introductory screens until you come to this one:



Here, the teacher explains that the universe is a 12-by-12 array of cells. Each cell holds exactly one of the following four colors: blue, red, green, or orange.

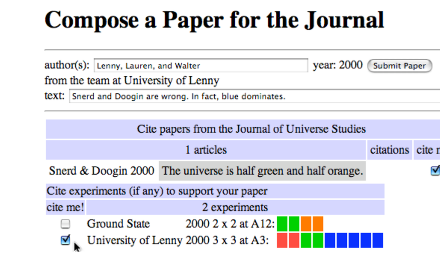
You can find out about the universe by performing experiments. There are two types of experiment: 3-by-3 and 2-by-2. When you perform that experiment—by specifying a 3x3 or 2x2 sub-array of the universe—you learn the distribution of colors within that small square, but not the colors' actual positions.

You and your group, a little mystified, decide to look at the 3x3 sub-array in the lower left. You specify it—in the prototype, you enter the coordinates of the upper-left corner (row 10, column 1)—and press **Do Experiment**. You learn that the 3x3 there contains two red, two green, and five blue cells.



You go back to the **Lobby** page and explore the other buttons. In the **Lab**, you see "See all results," which displays the results you just got. The **Library** button shows you this:

You know Snerd and Doogin; they're in another group. You click on the link and see their two-sentence "paper" and their data (the 2x2 at row 10 column 1 is two oranges and two greens). But from your data, you know that their conclusion was wrong. You go to your **Office** to Write a Paper. This leads you to a screen where you can compose a very, very short paper. You write, Snerd and Doogin are wrong. In fact, blue dominates. The referee (the instructor in this case) rejects your first attempt because you have neglected to reference Snerd & Doogin and your own experimental results. But you fix that (as shown) and resubmit.



Now the journal shows your paper as well.

Flushed with success, you and your group perform more experiments (deciding together, with some discussion, what experiments to do), using overlapping 2x2s to try and figure out which cells in your square have which colors. Lauren thinks the five blues are probably in the shape of an "L." Lenny thinks they're a "plus." Personally, you think they're an "X." But on submitting your fourth experiment—with only the Lenny Conjecture disproved—the computer informs you that you cannot afford the experiment. Talking with the other groups, you discover that experiments cost money—and that 2x2 experiments are more expensive than the 3x3s.

Twenty minutes have elapsed, and the instructor calls time. She leads a brief discussion of what has been discovered so far (a third group believes that the universe has a line of mirror symmetry on the main diagonal; a fourth has discovered that the center 2x2 is all red) and explains the schedule and criteria for new funds being added to your group's account. The next discussion will be on Friday; for now, she returns to the regular course content. At the end of class, she reminds you all to stay in touch with your group, and log back in—from home if necessary, but you can use the media center—to perform more experiments, read the Journal, and submit more papers.

What Really Happens?

Assessment

We want to figure out what, if anything, students are learning from these simulations. In addition, instructors may need to assess overall class performance or individual student performance.

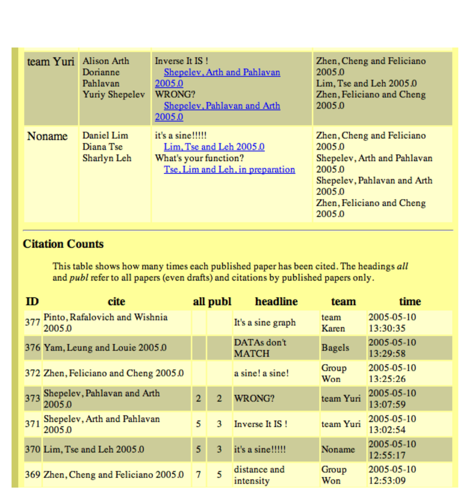
The journal is a record of the history of the scientific enterprise, and an obvious place to turn when we're looking for how to assess student understanding. Do student papers propose genuine hypotheses? How do students respond—using the journal—when data contradicts a current theory?

You can see some of that happening in the column at right, from a single period in a high-school physics class (Jeff Adkins, teacher). At the top, Hopwood et al. present the first all-universe low-resolution survey—but don't draw any conclusion, for example, about symmetry. You can see students trying to be quantitative about relative populations of different colors. Earlier (farther down) you can see a lively exchange about the color green, which gets more refined as time passes.

We can see that the students have a ways to go, but they were engaged, and they were writing about the science.

Beyond reading the journal, we can get the database it lives in to help us understand what's going on. Since most communication and all actions take place by typing, we can record all of those as the "history" of the simulated scientific endeavor. During or after the simulation, we can get any set of the information we want.

But there is too much to work with easily. What do we want for a display? Here is an example of part of a prototype instructor display:



At the top, you can see displays for two of the many teams in this class, showing what papers they have written and what papers they have read. At the bottom is a display of citations showing how many citations each published paper has received.

These displays are helpful but far from ideal. What can we include that best represents what students have done? How should we incorporate our own observations during class? How can we use this kind of assessment to encourage students to do more, and be more thoughtful in their work?

Another possibility is some paper-an-pencil instrument that assesses understanding of the nature of science. We are leery of such things, but would like to know about any you're aware of!

Some Papers from a High School Class

(latest papers first)

Hopwood, Foster and Hinkle 1969.1

```
This is what our pattern looks like so far:
(in 3x3 boxes)

1x1=0513 1x4=3204 1x7=3204 1x10=0513
4x1=3204 4x4=3105 4x7=3105 4x10=3204
7x1=3204 7x4=3105 7x7=3105 7x10=3204
10x1=0513 10x4=3204 10x7=3204 10x10=0513

References: none

New Experiments:
[r:3, b:2, g:0, o:4] @(7, 1)
[r:0, b:5, g:1, o:3] @(10, 1)
[r:3, b:2, g:0, o:4] @(4, 1)
[r:0, b:5, g:1, o:3] @(1, 1)
[r:3, b:2, g:0, o:4] @(1, 4)
[r:3, b:0, g:0, o:6] @(5, 4)
[r:3, b:1, g:0, o:5] @(7, 7)
[r:3, b:1, g:0, o:5] @(7, 4)
```

Williams, Gomez and Downes 1969.0

```
Can we have more money because we want to explore row 10
columns 1-3 because no one is talking about that region or
researched that region please give us money!!!!!
```

Brittner and Davis (1969.0)

```
Orange is not always the same number.

References: Archaga 1969.1

New Experiments:
[r:0, b:1, g:0, o:3] @(3, 4)
[r:2, b:0, g:0, o:2] @(4, 6)
```

Archaga (1969.1)

```
Orange is consistant in the universe, meaning that it is
always the same number.

References: none

New Experiments:
[r:0, b:5, g:1, o:3] @(1, 1)
[r:2, b:4, g:0, o:3] @(8, 10)
[r:0, b:5, g:1, o:3] @(10, 10)
[r:0, b:5, g:1, o:3] @(1, 10)
```

Hansen and Hamilton (1969.2)

```
The ratio of blue to orange is 17 to 19. orange is the most
dominant color.
```

Pruett, Quintana and Sico (1969.1)

```
There are no greens in the middle.

New Experiments:
[r:1, b:0, g:0, o:8] @(5, 6)
[r:4, b:3, g:0, o:2] @(9, 6)
[r:3, b:2, g:0, o:4] @(4, 10)
```

Sayo and Maloles (1969.0)

```
The universe is mostly made up of orange. The orange to green
ratio is 32:3. The orange to blue ratio is 32:19. The orange
to red ratio is 2:1. Orange is the most dominant color.
```

Finn and Jereb (1969.1)

```
Green is the least popular color in the Universe.

New Experiments:
[r:3, b:2, g:0, o:4] @(4, 1)
[r:3, b:1, g:0, o:5] @(4, 4)
[r:3, b:1, g:0, o:5] @(4, 7)
[r:0, b:5, g:1, o:3] @(10, 1)
```

Gomez, Williams and Downes (1969.0)

```
we have noticed that green is not a popular color within the
grid, and blue and red are popular from what we have seen.
```

Davis and Brittner (1969.0)

```
Hansen and Hamilton are wrong. There IS green in the universe.
HA!

References: Hansen and Hamilton (1969.0)

New Experiments:
[r:0, b:2, g:1, o:1] @(1, 2)
```

Hansen and Hamilton (1969.0)

```
there is no green in the universe.

New Experiments:
[r:4, b:3, g:0, o:2] @(5, 2)
[r:2, b:2, g:0, o:5] @(7, 3)
[r:2, b:3, g:0, o:4] @(4, 2)
```

To Use Your Own Computer

Here at this session, my laptop is acting as a server on its own wireless network.

- Find and join the network named **eeps**. There is no password necessary.
- Using your browser, navigate to **http://eeps.local/~tim**. That should get you a screen like this:

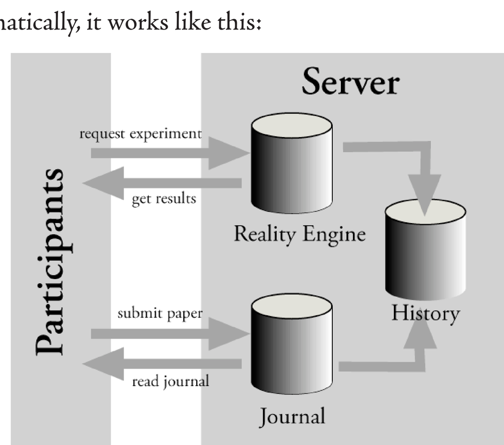
- Choose **Register**. Enter whatever information you like; you can lie with impunity!
- Choose **Login**, and pick a world to join. Follow your nose from there, joining whatever team you choose.

Eventually, we'll have a couple sample scenarios up on the *real* web so you can play at home. They'll be at **http://www.eeps.org**, we hope by September.

Computer Geek Corner

The whole thing is implemented in php and MySQL, running in conjunction with the Apache web server that comes standard with Mac OS X.

Schematically, it works like this:



It is no accident that there is no direct connection between the Journal and Reality.

A Teacher's Report

In a high-school class in 2004, the teacher reported that even in its prototype state, the activity (followed by discussion) was able to illustrate the following concepts within a single class period:

- Sometimes scientists must work with incomplete information.
- A planned, systematic experiment reveals more than trial and error.
- Collaborative efforts can capitalize on investments already made elsewhere.
- A hypothesis is testable if an experiment can be designed to probe its consequences (this is particularly important as most high school students do not move beyond 'a hypothesis is a testable educational guess').
- A theory can guide the development of hypotheses.
- More detailed experiments are more expensive.
- There is not an unlimited amount of money available for research.
- Sometimes all you can do is look for patterns in other people's data.

In the vignette, and in the real classroom, the students began to understand what it means to do science. They explored a new field of knowledge. They wrote papers and cited the work of others. They decided which experiments to perform. Some theories rose to prominence and were later discarded as simplistic and naïve. This is different from learning concepts and skills. In itself, the simulation does not teach the nature of science—it will take attention from the teacher to turn the raw experience into learning, and we are continuing to explore what's necessary. But the simulation gives students the experiences they will need to refer to; that is, now they have been scientists, and this is more powerful than reading about them.

Adkins's classes are typical of those with which we work in that they are diverse ethnically, economically, and in intention. These are not all college-bound students; all students need this.

Things we want to Know

This project is in its infancy. Here are a number of things we really hope to find out. Any of your advice is most welcome!

What enduring learnings really take place? What needs to be in the debriefing(s) to make that happen?

A related question: what assessment tools are available? What do they really tell us?

- How much class time does this really take, and what kind of learning to you get for what investment of class time?
- Under what circumstances can and will students work on this outside of class? (One timesaving possibility is that, except for an introduction, class time is used only for basic logistics and debriefing; students use out-of-class web access to do experiments, write papers, etc.)
- Could a class (and would a class) do a simulation like this over a long period of time, not much time per week? Is there any advantage to that scheme?
- What about a simulation that incorporates students from more than one class or more than one school? If it's on the web, it can be done. Is it a good idea? What extra richness comes from setting that up?
- The 4-color scenario is rich but abstract. How important is it to have content-specific scenarios? What scenarios should they be? Can we make them without losing the big picture of science?

Tim Erickson
Epistemological Engineering/eeps media
5269 Miles Avenue
Oakland, CA 94618–1044
510.653.3377
tim@eeps.com, http://www.eeps.com

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