Title: Physics Education Research: Helping Students Become Better Scientists

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Abstract: Physics Education Research (PER) is a blossoming subfield of physics that is changing the way students become physicists. Our research involves the transformation of the lab portion of a first-year enriched physics course through the implementation of â€œinvention activities:â€• discovery-learning activities that ask students to â€œinventâ€• a solution to a problem before being taught the expert solution. The combination of invention activities and tell-and-practice methods has been shown to lead to better student learning and performance on transfer tasks, as compared to tell-and-practice methods alone (Roll, Aleven & Koedinger, 2009; Schwartz & Martin, 2004). In addition, scaffolding invention activities using domain-independent metacognitive prompts can support students through the invention process, leading them to attend to more features of the domain and reason at a deeper level (Roll, Holmes, Day & Bonn; submitted). Our current study further investigates this theory by expanding the treatment across a four-month term and using faded levels of scaffolding. Using interactive learning environments (ILE), five inventions in the domains of statistics and data-analysis were given to students and various assessments were administered to measure performance on domain-level knowledge and â€œinvention skills.â€• I will present preliminary results from this and previous studies.

What's wrong with traditional instruction and labs?

Students coming into **and** leaving first-year physics have poor data-handling skills (Day & Bonn, 2011)

Students memorize formulas

- Little conceptual understanding of mathematical equations
- Struggle to transfer learning over time and to new problems

Students generally aren't physicists!

What can we do about it?

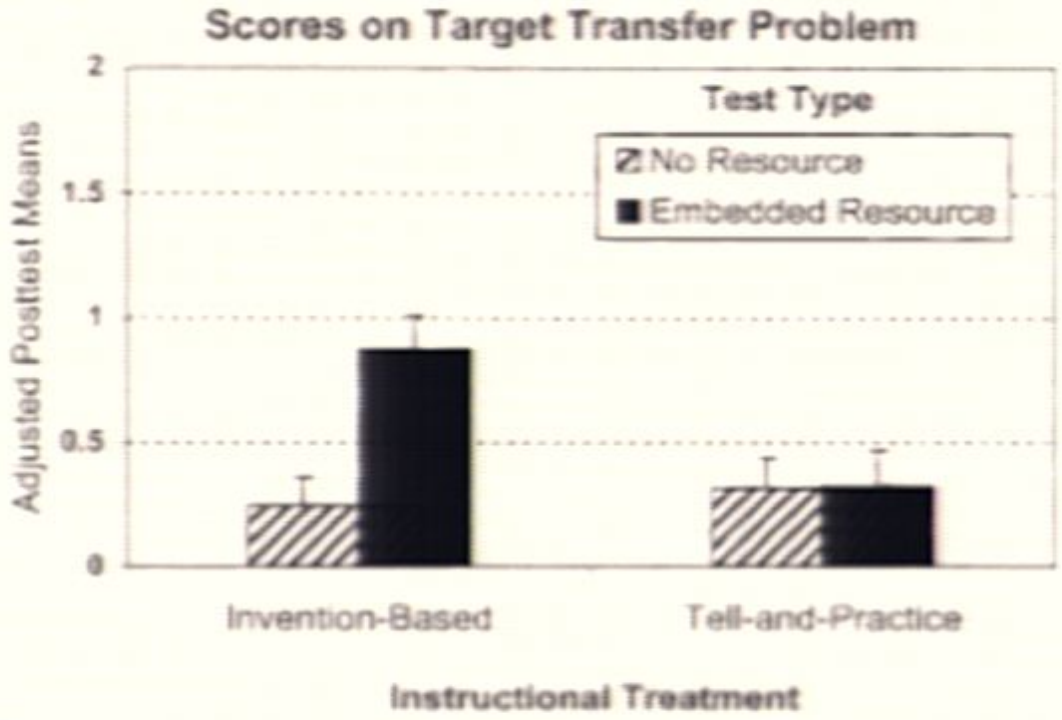
- Re-focus labs
  - Away from following recipes in order to observe concepts they've already seen in class
  - Towards skills they'll find useful as scientists in any field (Day & Bonn, 2011)

- Invention activities
  - Students *invent* a solution to a problem being taught how to solve the problem
    - Mathematical formulas, in this case

Invention as Preparation for Future Learning

Invention as Preparation for Future Learning

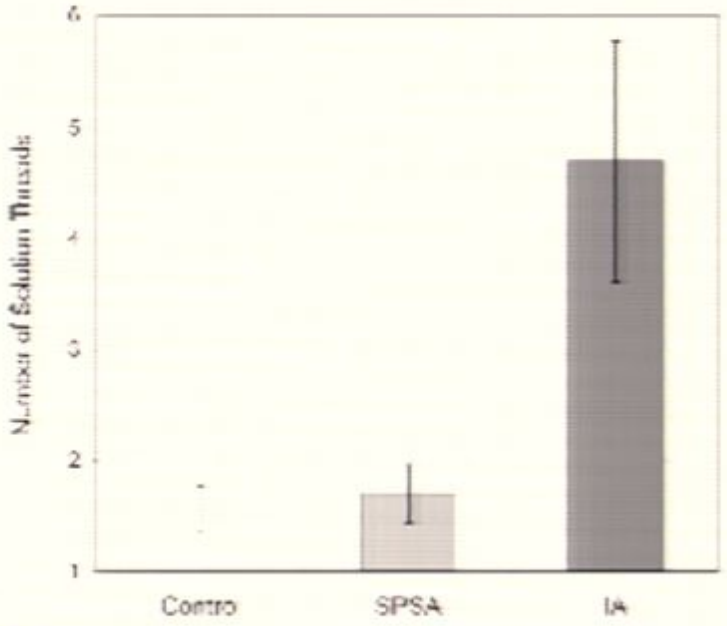
Invention Activity → Direct Instruction → Practice

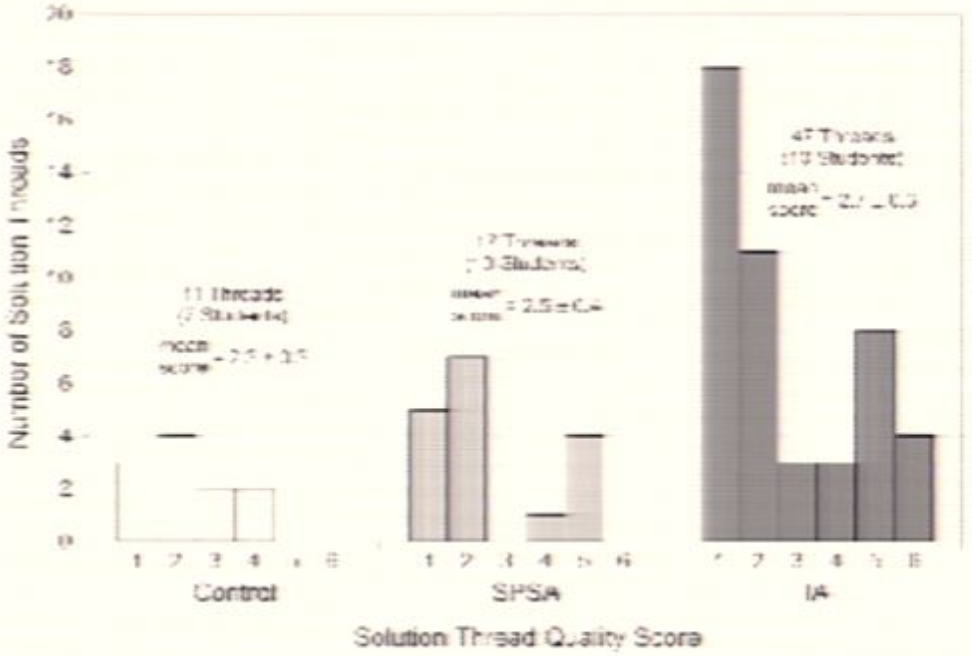


Schwartz & Martin, 2004

Invention as Preparation for Future Learning

Invention Activity → Direct Instruction → Practice

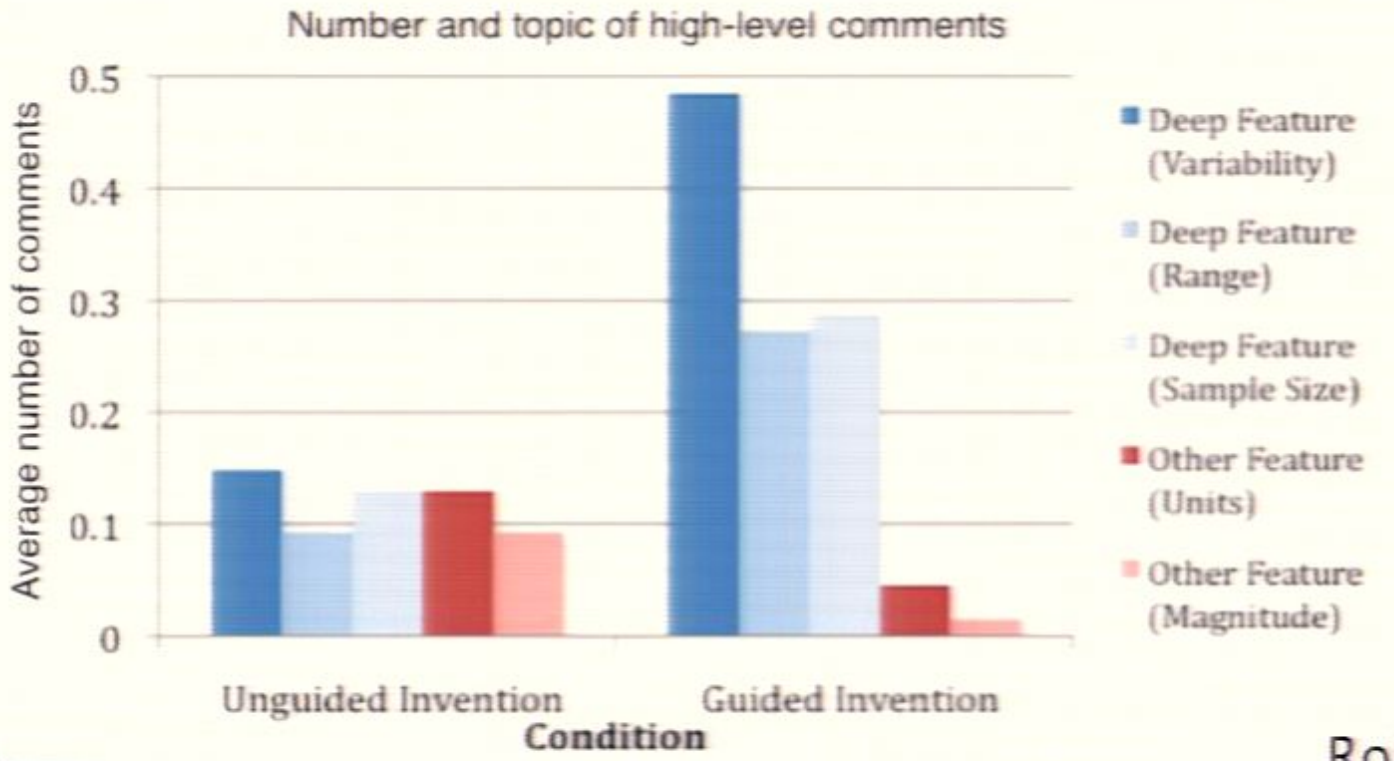




Taylor, et al. (2010)

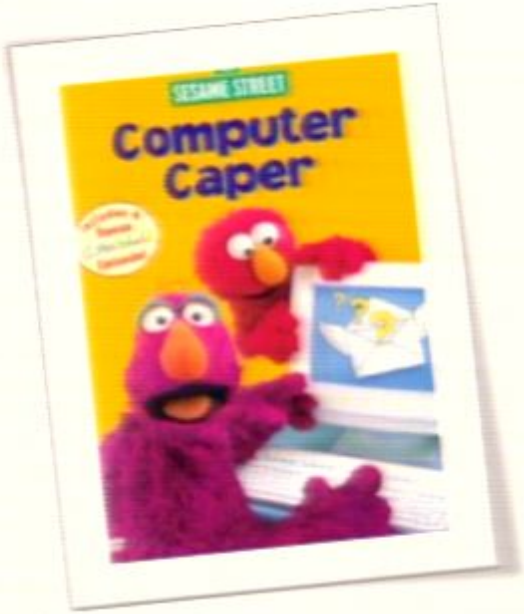
Invention as Preparation for Future Learning

Invention Activity → Direct Instruction → Practice



Roll, et al. (accepted)

The iLab



Interactive Learning Environment (ILE) for inventions

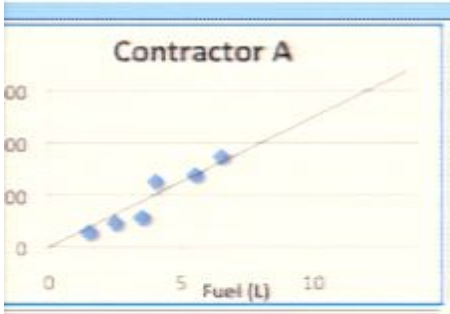
- Classroom benefits
  - Transfer inventions to various classrooms
  - Students work independently with embedded guidance
  - Straightforward manipulations can create new activities
  - Paperless labs

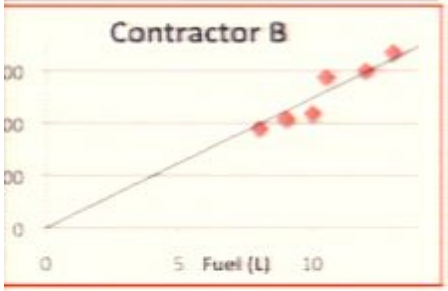
- Experimental benefits
  - Collects time-stamped data of students' reasoning process
  - Efficiently randomize students into conditions in class

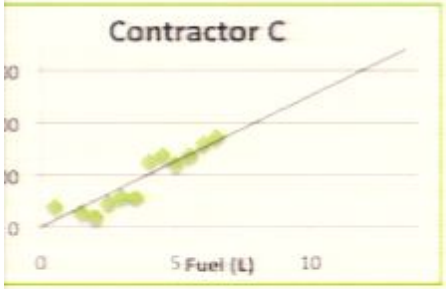
Constructing an invention activity

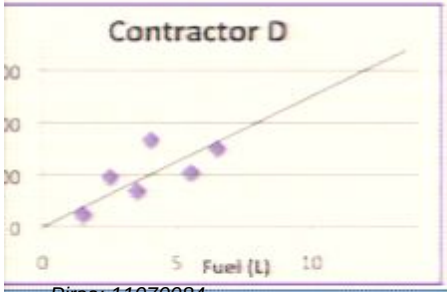
- Start with a clear goal

Goal: Determine Uncertainty in Slope









Initial Final

ShowData

Intro

Fuel Consumption

At the end of an experiment, you often need to make a judgment about the reliability of a fit to an entire set of data. In particular, you often need to determine the uncertainty in a fitting parameter such as a slope.

In this exercise, imagine that you are testing the fuel efficiency of a new vehicle and you have hired four outside contractors to do measurements of how far the vehicle can drive with different amounts of fuel. They have all gathered data somewhat differently and you have to judge which one of the contractors can give you the most reliable measurement of fuel efficiency. The slope of the best fit in each graph is the fuel efficiency in units of km/litre and all of the fits have come very close to 50 km/litre. Your task is to invent a formula that can be applied to these four data sets in order to determine the uncertainty in this slope.

Note that the model is a straight line going through the origin:

Distance = 50 * (Fuel Consumption)

Slope = (50 ± σ_m) km/litre

The ultimate goal here is to determine σ_m, the uncertainty in the slope.

Data

Part 1

Part 2

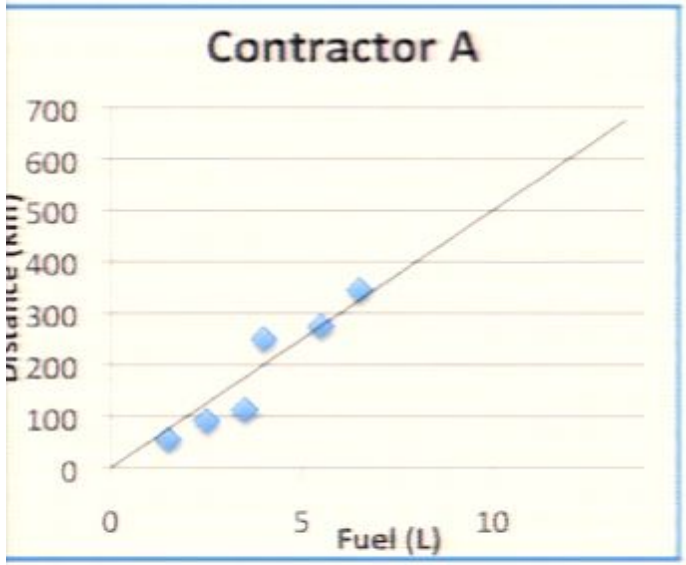
Part 3

Part 4

Constructing an invention activity

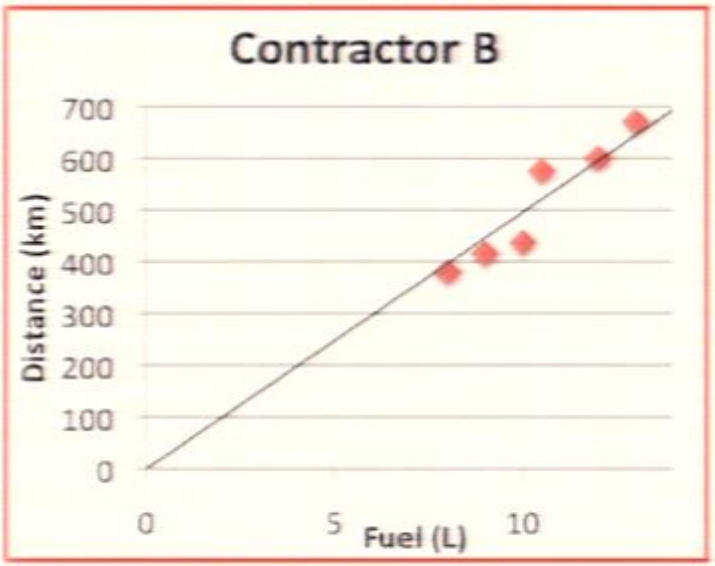
- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)

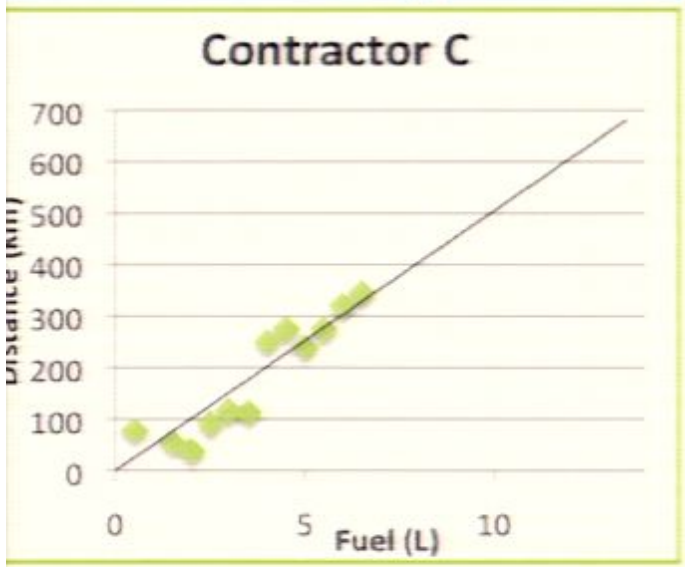
Contrasting Cases



Contractor A	
Fuel (Litres)	Distance (km)
1.5	54.6
2.5	90.7
3.5	112.5
4.0	250.2
5.5	274.9
6.5	345.7

Contractor B	
Fuel (Litres)	Distance (km)
8.0	379.6
9.0	415.7
10.0	437.5
10.5	575.2
12.0	599.9
13.0	670.7

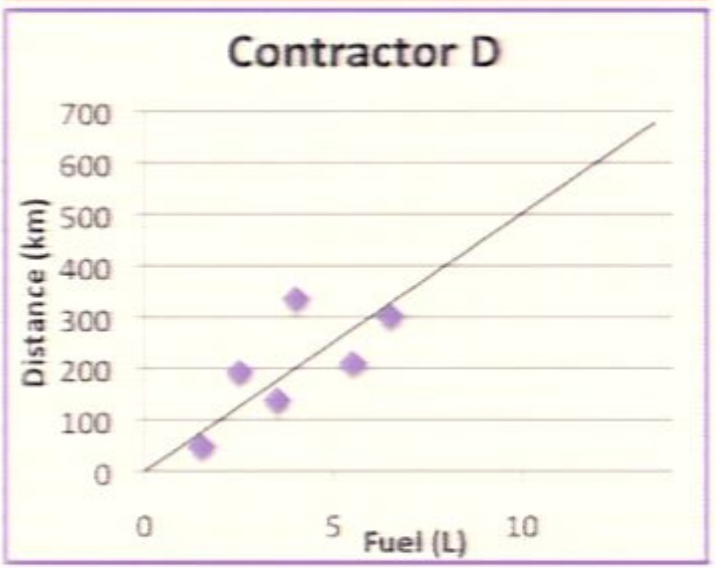




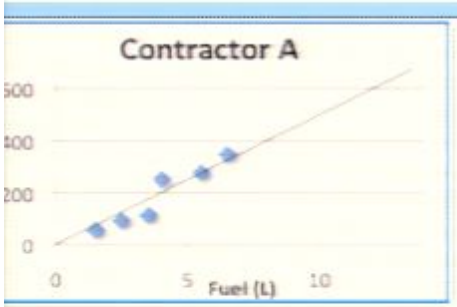
Contractor C	
Fuel (Litres)	Distance (km)
0.5	77.3
1.5	54.6
2.0	37.5
2.5	90.7
3.0	115.7
3.5	112.5
4.0	250.2
4.5	275.2
5.0	239.5
5.5	274.9
6.0	320.7
6.5	345.7

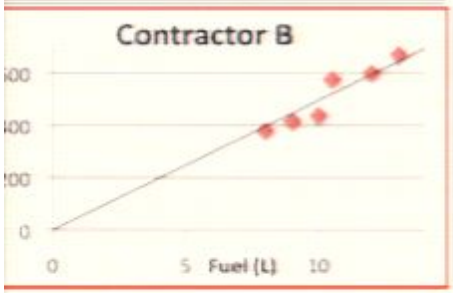
Contractor D	
Fuel (Litres)	Distance (km)
1.5	47.5
2.5	192.3
3.5	137.8
4.0	335.0
5.5	209.4
6.5	301.2

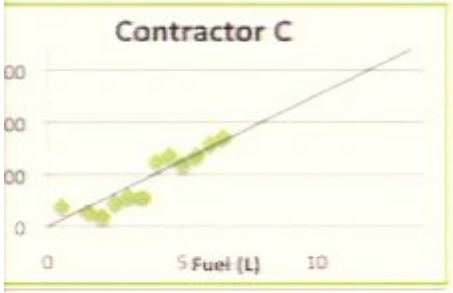
Zoom Out

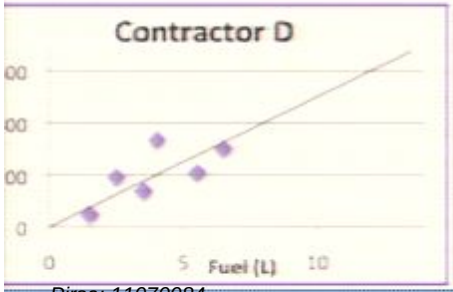


Comparing cases









Initial Final

ShowData

Intro

Data

Part 1

In each of the following pairs, which of the contractors does a better job of measuring the slope of the data and why?

A vs B – ? –

A vs C – ? –

A vs D – ? –

Please rank the four graphs according to the accuracy of the slope. (1 = best, 4 = worst and a tie can be expressed by giving graphs the same value in their ranking.)

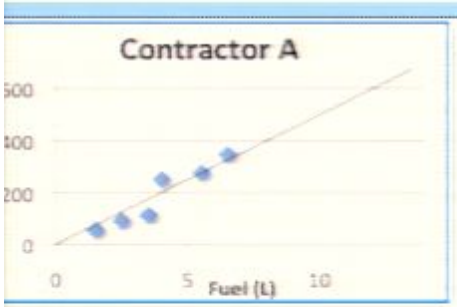
A B C D

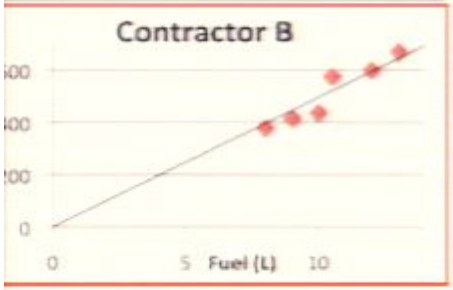
Part 2

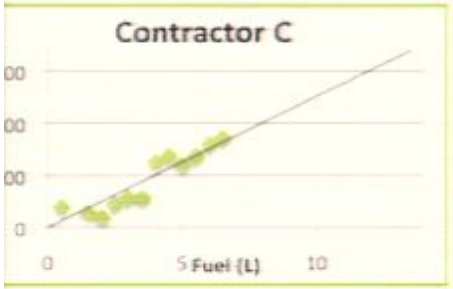
Part 3

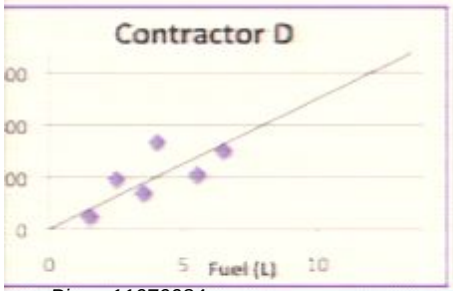
Part 4

Comparing cases









Initial Final

Intro

Data

Part 1

In each of the following pairs, which of the contractors does a better job of measuring the slope of the data and why?

$$(\delta m)^2 = \frac{1}{N} \frac{\sum_i \left(y_i - f(x_i)\right)^2}{\sum_i x_i^2}$$

st, 4 = worst and a tie can be expressed

Part 2

Part 3

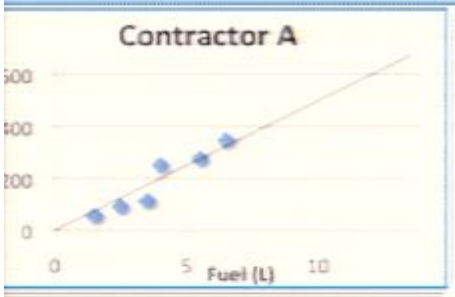
Part 4

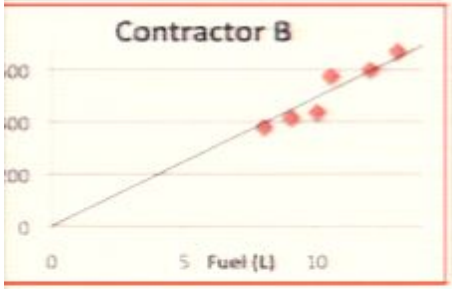
ShowData

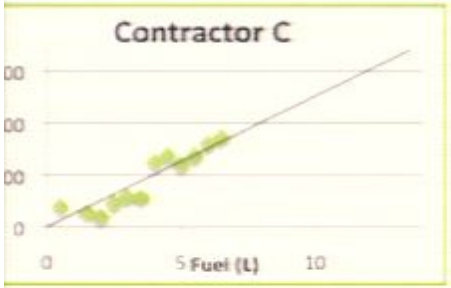
Constructing an Invention Activity

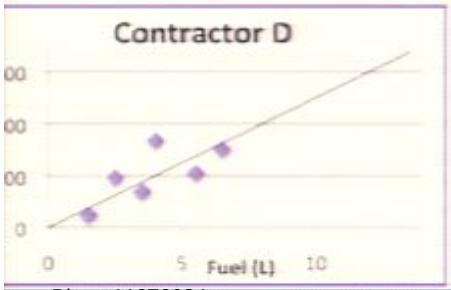
- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)
- Connect features to quantitative models
  - Invent a formula

Inventing a model









Initial Final

ShowData

Intro

Data

Part 1

Part 2

Invent a model to compute the uncertainty in the slope for each graph. Use the space to build a general formula for the slope uncertainty that can calculate a single value for each contractor. You may use the operators and symbols in the Equation Editor (below) as well as the keys on your computer keyboard.

Rules:

1. Each line applies to the whole data range provided, so a graph only gets a value for the slope uncertainty.
2. The exact same model must apply to each graph.
3. A smaller uncertainty implies that the slope was measured more accurately.
4. The model must incorporate the criteria described in Part 1.

Please explain how your formula relates to your justifications for higher quality slopes from Section 1.

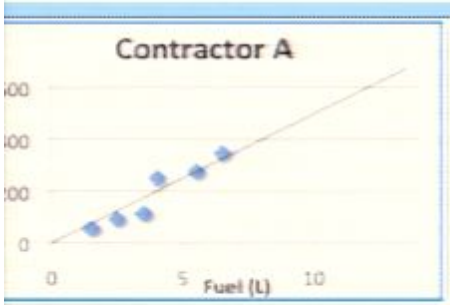
Part 3

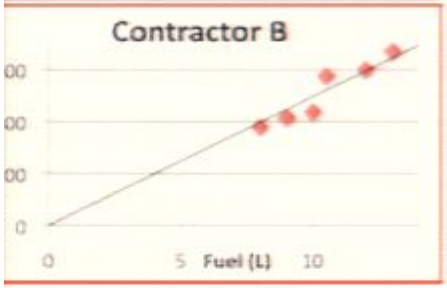
Part 4

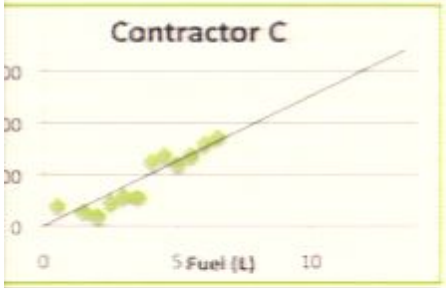
Constructing an Invention Activity

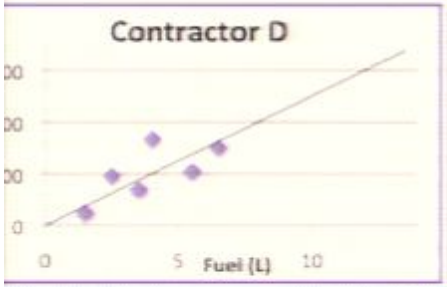
- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)
- Connect features to quantitative models
  - Invent a formula
- Implement the formula

Implement your formula









Initial Final

ShowData

Intro

Data

Part 1

Part 2

Part 3

With the data provided, use your solution to calculate the slope uncertainty for all four models. Record your values here.

A B C D

Please rank the four graphs according to the uncertainties in the slope of their lines. (1 = best, 4 = worst and a tie can be expressed by giving graphs the same value in their ranking.)

A B C D

Please upload your spreadsheet file here (Either *.ods, *.csv or *.xls, *.txt file types).

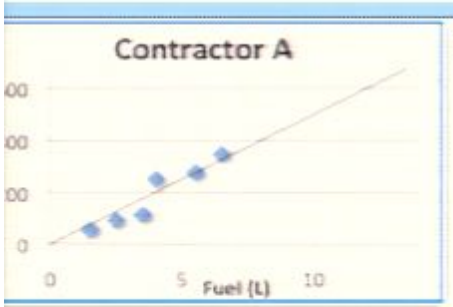
Upload File No file uploaded

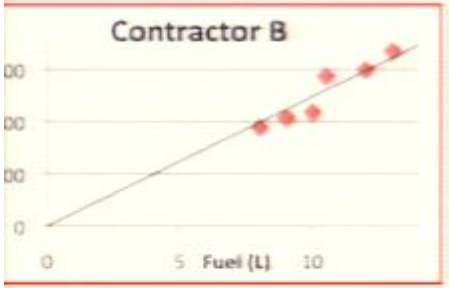
Part 4

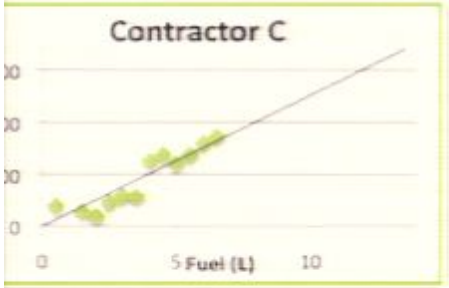
Constructing an Invention Activity

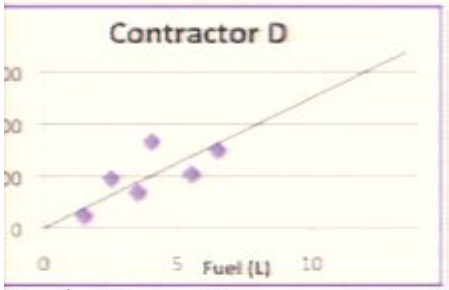
- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)
- Connect features to quantitative models
  - Invent a formula
- Implement the formula
- Evaluate the results

Evaluate your model









Initial Final

ShowData

Intro
Data
Part 1
Part 2
Part 3
Part 4

Does your final ranking agree with your initial ranking? --Yes/No--

Please explain the strengths and weaknesses of your model.

Please ensure that the formula in Section 2 reflects the calculations performed in Section 3. Continue

Done

Constructing an Invention Activity

- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)
- Connect features to quantitative models
  - Invent a formula
- Implement the formula
- Evaluate the results
- Collaboration

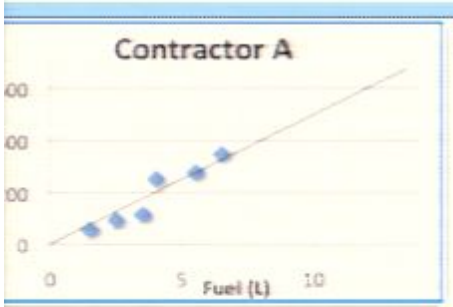
Future research

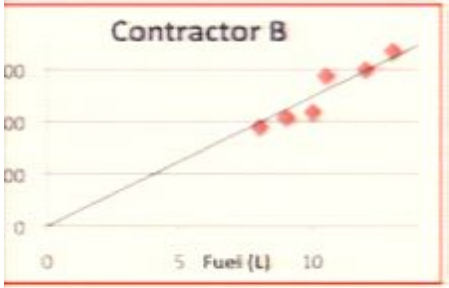
- Effects of different levels of guidance built into the system
- Applying it to other courses and with other instructors
- Better logging of student actions and input
- Embedded flash spreadsheet
- Assess reasoning ability (How?)
- …?

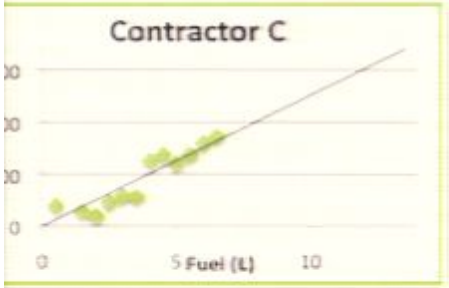
In Summary…

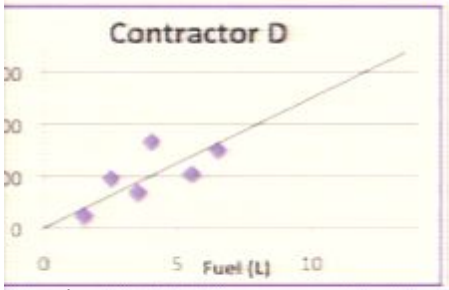
- Labs should be more than just a cooking class
- Invention activities can help students discover concepts and pick up science skills along the way
- The iLab will help get invention activities in the classroom

Evaluate your model









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Constructing an Invention Activity

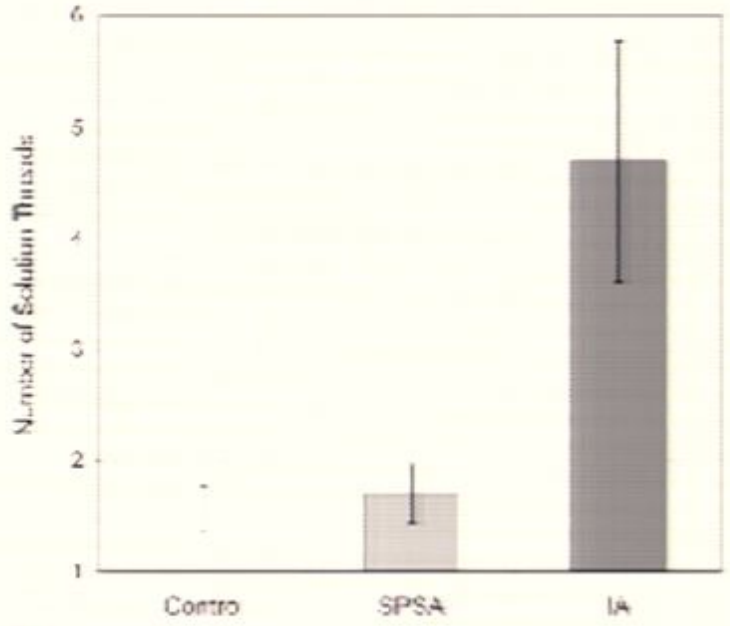
- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)
- Connect features to quantitative models
  - Invent a formula
- Implement the formula

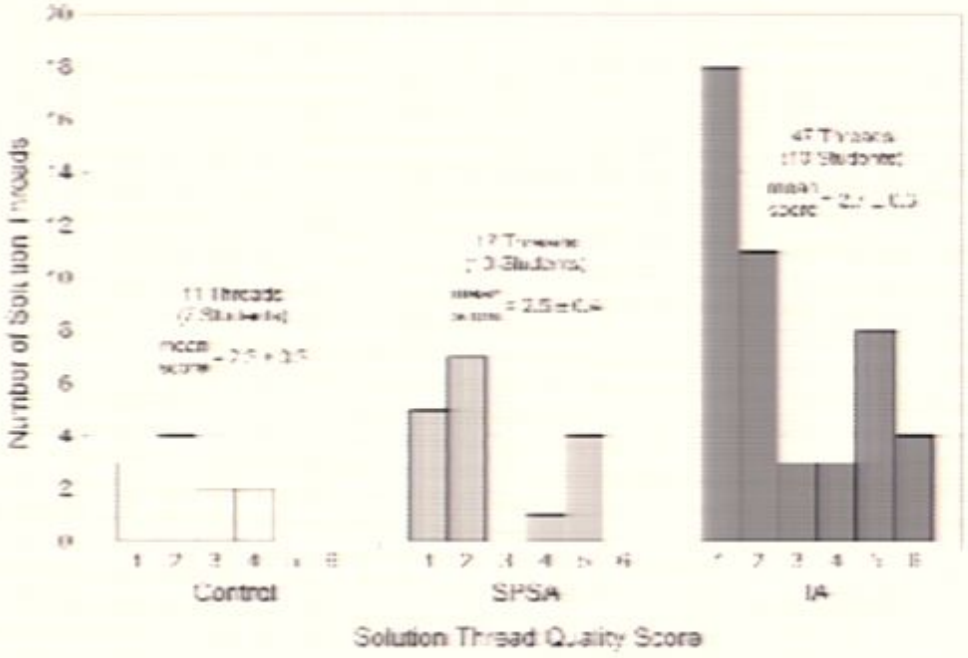
Constructing an invention activity

- Start with a clear goal
- Present the data with features explicitly varied
  - Allow students to observe which features are important and relevant (Schwartz & Bransford, 1998)

Invention as Preparation for Future Learning

Invention Activity → **Direct Instruction** → **Practice**





Taylor, et al. (2010)

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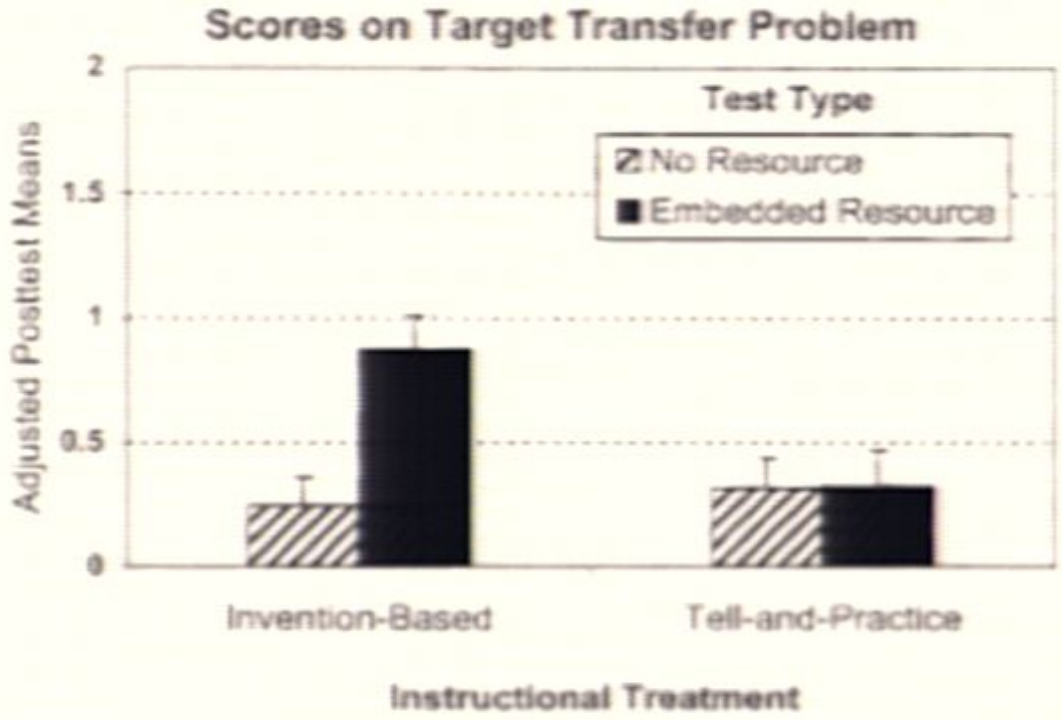

Schwartz & Martin, 2004