preparing students for learning through invention activities

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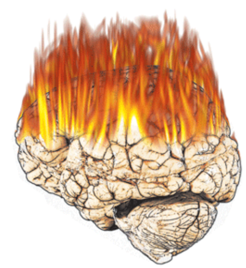
the problem

1st year physics laboratories are often driven by a mix of goals: illustration or discovery of basic physics principles; a myriad of technical skills (e.g., specific equipment, data analysis, report writing); etc.

long list of learning goals

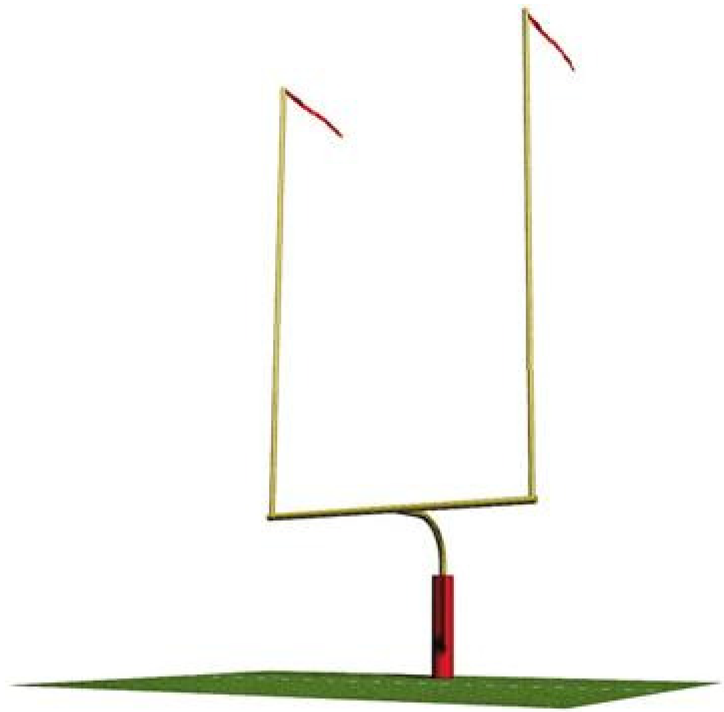


cognitive overload

While students might be able to reproduce certain technical manipulations of data, as novice thinkers they lack the mental scaffolding that allows an expert to organize and apply this knowledge.

* Recent studies[1] indicate that the 'cookbook' approach leaves students with a poor conceptual understanding of one of the most important features of laboratory physics and of the real world of science, in general: the development of an understanding of the nature of measurement and its attendant uncertainty.

the goal



To put novices on the path to expertise, so that they will be able to transfer their knowledge to novel situations.

the method

One proven method[2] of getting students to explore underlying structure is to have them complete ‘invention activities’ as a preparation for future learning.

Invention activities are brief, highly-structured activities which actively engage the students and are intended to stimulate creative thinking. They are intended to precede both explicit instruction and reinforcing practice.

In these tasks[3], students are provided with a set of very deliberately selected cases, and their aim is to invent a compact description (typically mathematical) that generalizes across the given cases. They need not identify the correct answer, as the purpose of the exercise is to groom students for future learning: the invention activity facilitates students in detecting important structure in the given cases and in building an organizational scaffolding that prepares them to understand conventional descriptions. Once the activity has been completed, the students can then be told the expert knowledge and then follow-up with practice.

* Studies[4] on the added benefits of the invention-then-telling approach reveal profound differences when students are presented with more expert-like tasks that include learning new related ideas and applying their knowledge to new situations.

invention activity features

✔ clear goal

The task should present a clear and challenging goal of developing a compact and consistent description or representation of the fundamental attributes across the cases.

The solution usually involves integrating several features into one single representation (e.g., a ratio).

invention activity features

✔ contrasting cases

The task should include multiple cases simultaneously.

Contrasting cases assist in the development of early knowledge because they help learners to notice new features or structure and to develop new interpretations.

Cases should systematically vary on key parameters so students try to see how these variations relate at a deeper, structural level.

A good test of cases is to consider whether the cases are structured so that a reasonable (but incorrect) description based on a subset of them would fail to work for the remainder.

invention activity features

✔ student collaboration

The task should be done by pairs or groups of students, which carries the advantages of a greater number ideas and some peer instruction.

invention activity features

one must also pay close attention to...

- ✔ context: the task should involve things relatively familiar and meaningful to the students
- ✔ level of difficulty: the task should be structured so that students typically achieve partial success (e.g., always capable of getting started but seldom finding the 'correct' answer)
- ✔ absence of jargon: the task should be free from subject-specific vernacular, which commonly triggers students to attempt recall of formulae they have already learned rather than inducing a response more closely related to dealing with the development of a new process

example invention activity

part I

✔ clear goal

Outline a procedure for converting the data provided into a useful graphical representation and show the resulting graph for each data set. The same procedure must be used for each data set.

✔ contrasting cases

Students are provided with four data sets which have the features:

- $N = 10$; $\mu = 10$; $\sigma = 0.25$
- $N = 20$; $\mu = 10$; $\sigma = 0.25$
- $N = 10$; $\mu = 11$; $\sigma = 0.25$
- $N = 10$; $\mu = 10$; $\sigma = 0.50$

example invention activity

part II

✔ clear goal

Invent a procedure for computing the 'blue-ribbon factor' for each data set (i.e., a measure of the data's reliability).

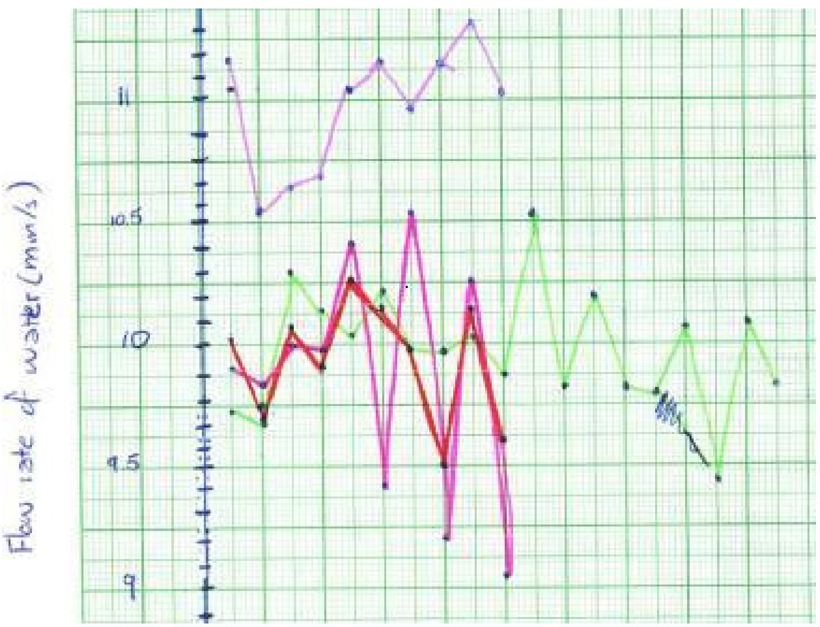
A small 'blue-ribbon factor' means more reliable data.

There is no single way to do this, but the same procedure must be used in all four cases.

Write down your procedure and compute the 'blue-ribbon factor' for each data set.

From this, rank the data sets in order of best to worst.

example student solutions

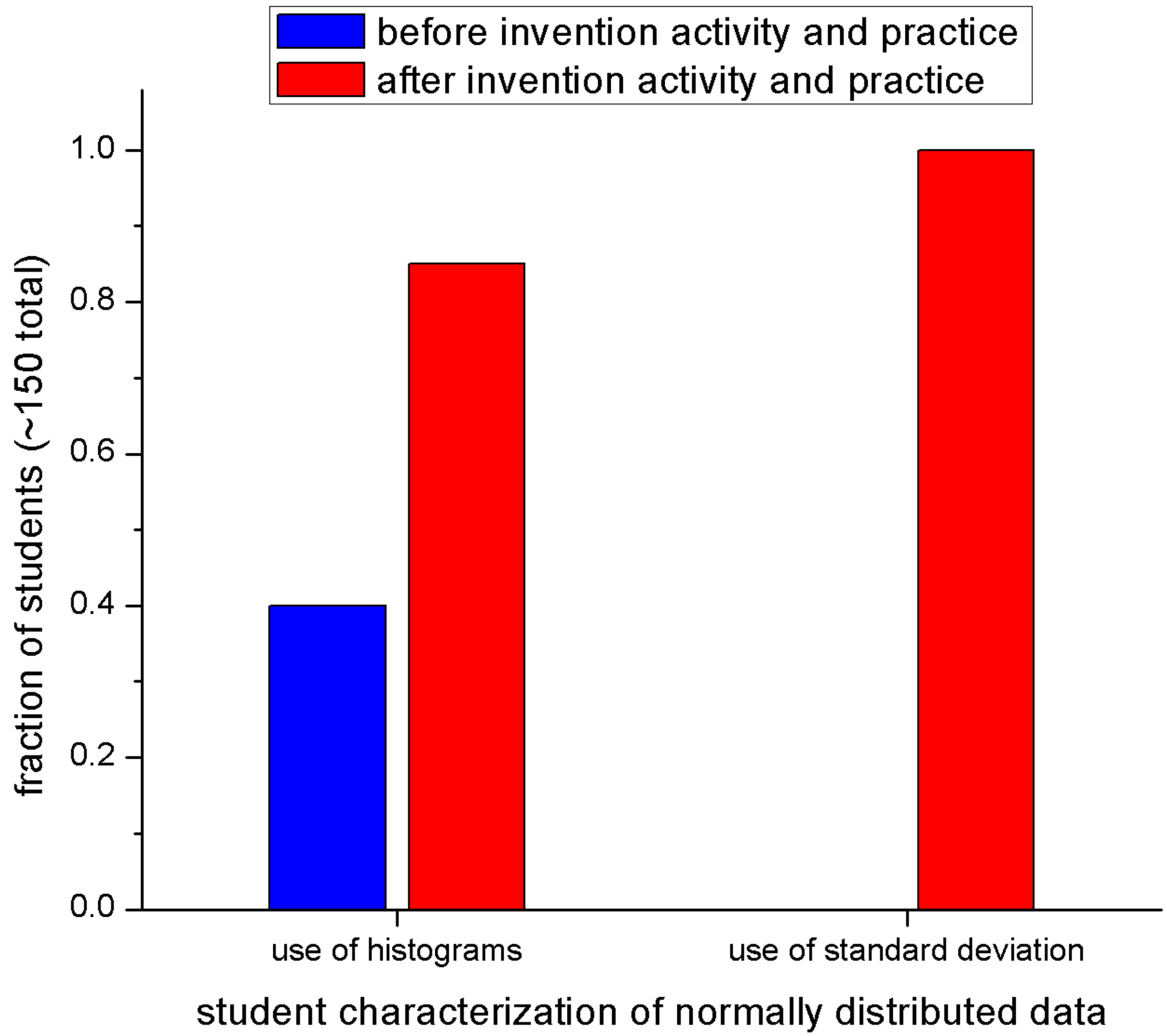


$$b.r.f. = \frac{1}{N}(y_{max} - y_{min})$$

$$b.r.f. = \sum_{i=1}^{10} |y_i - \bar{y}|$$

failure to transfer from high school

student characterization of data



another example invention activity

✔ clear goal

The slope of the best fit in each of the graphs below is the fuel efficiency, in units of km/L.

All of the fits have come very close to 50 km/L.

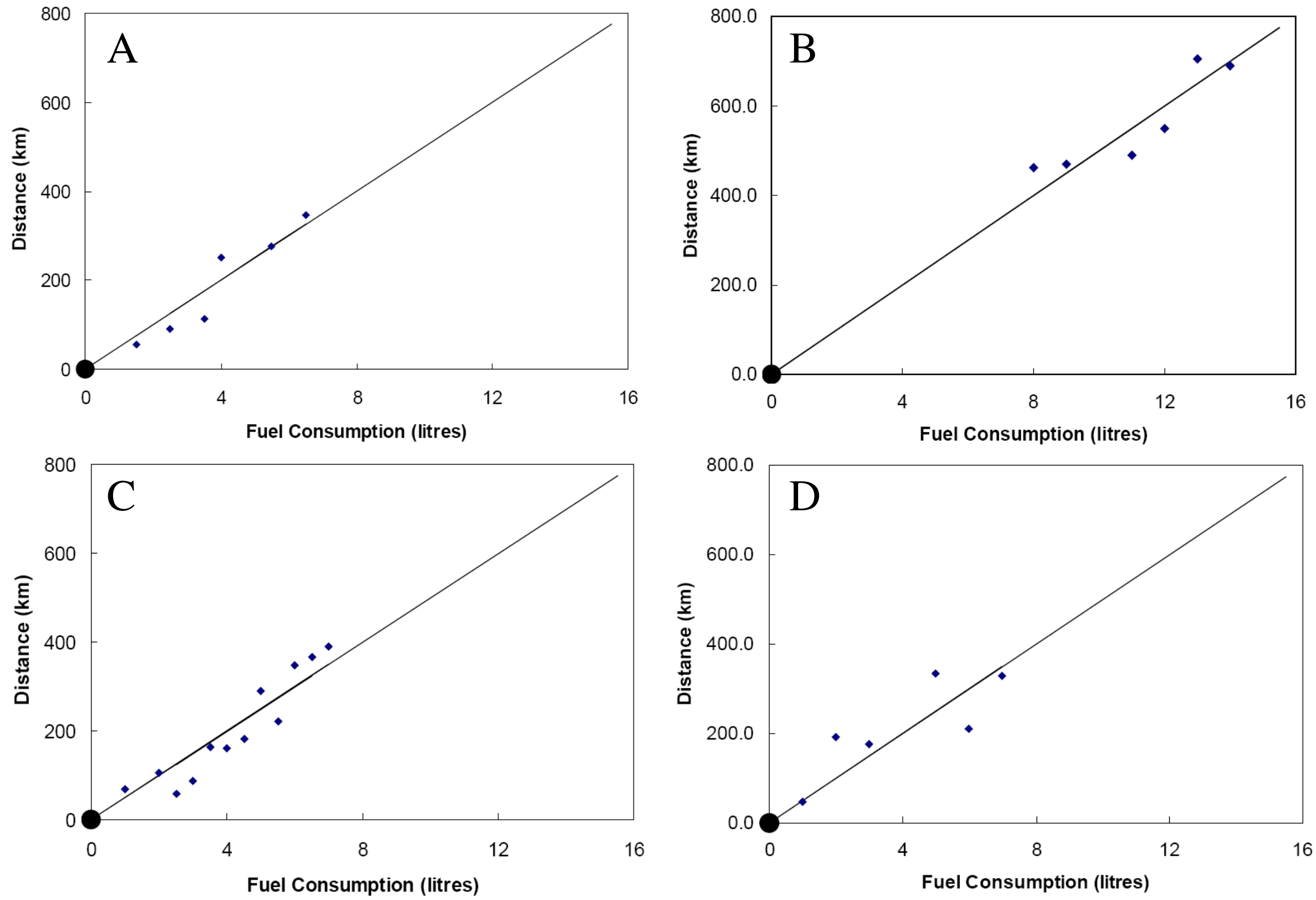
Your task is to invent a formula that can be applied to these four data sets in order to determine the uncertainty in this slope.

$$\text{slope} = (50 \pm \sigma_m)\ \text{km/L}$$

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

another example invention activity

✔ contrasting cases



example student solutions

$$\sigma_m = \frac{\sum_{i=1}^{N} \sqrt{\left| y_i - 50\mathrm{x}_i \right|}}{N}$$

$$\sigma_m = \frac{1}{N} \sum_{i=1}^{N} \frac{x_i}{x_{max}} \left| 50 - \frac{y_i}{x_i} \right|$$

$$\sigma_m = \sqrt{\frac{\frac{1}{N-2} \sum_{i=1}^{N} \left(y_i - 50\mathrm{x}_i \right)^2}{\sum_{i=1}^{N} \left(x_i - \bar{x} \right)^2}}$$

* Please see the poster by Natasha Holmes, called “Using Invention Tasks to Help Students Become Better Scientists”, for question related to the support of invention activities.

References

1. T. S. Volkwyn, S. Allie, A. Buffler, F. Lubben "Impact of a conventional introductory laboratory course on the understanding of measurement," *Phys. Rev. ST Phys. Educ. Res.*, 4, 010108-1:10 (2008).

2. Schwartz, D. L., Martin, T. "Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction," *Cognition and Instruction*, 22(2), 129–184 (2004).

3. Adams W., Carl Wieman C., and Schwartz D. "Teaching Expert Thinking," *at http://www.cwsei.ubc.ca/resources/instructor_guidance.htm*.

4. Schwartz, D. L., Bransford, J. D., Sears, D. L. "Efficiency and Innovation in Transfer," *in J. Mestre (Ed.), Transfer of Learning from a Modern Multidisciplinary Perspective*, 1-51 (2005).

Acknowledgments

We gratefully acknowledge the assistance of Hiroko Nakahara, Brad Ramshaw, Dan Schwartz, and Carl Wieman, each of whom provided useful comments towards the creation and development of the invention activities.

This work has been supported by UBC through the CWSEI.