Physics Lab Diagnostic and Teaching by Building from Student Invention

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What is the problem?

The primary aim of the ScienceOne and Physics 107/109 physics lab course is not to teach particular physics concepts or to reinforce what is taught in lectures; rather, the goal is to leave students with skills and attitudes that will be of value no matter what may be their later academic path. Beyond a variety of technical skills, the students learn how to make observations and measurements, build models that fit those measurements, and derive meaning from the success or failure of those models.

The problem is that teaching such skills is exceedingly difficult and has not been optimized.

How do we approach the problem?

- determine what we want the students to learn in the course
  - learning goals are created in the form of explicitly stating what the student will be able to do by the end of the course
    - e.g., the student will be able to make a two-dimensional scatter plot of data on linear scales

- assess students' abilities at the beginning of the course
  - **physics lab diagnostic** administered as a pre-test

- teach the students the skills we want them to have
  - **invention activities** employed for many in-class assignments

- assess students' abilities at the end of the course
  - **physics lab diagnostic** administered as a post-test

- celebrate/commiserate with colleagues

Physics Lab Diagnostic

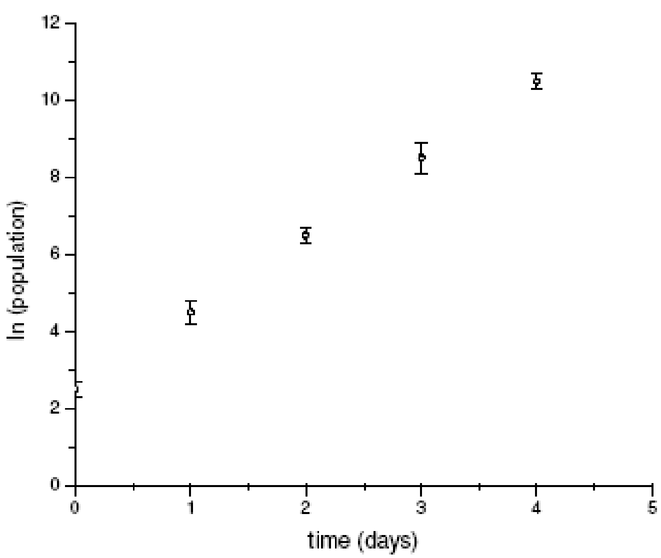
- 10 multiple choice questions
  - distractor options based on student answers from earlier written version
  - questions validated through 12 student interviews
- probes the students' ability to:
  - handle measurement uncertainty
  - make connections between data and mathematical models
  - calculate basic statistics
- administered as a pre-test and as a post-test
  - 15 minutes to complete
  - not allowed to use a calculator

Physics Lab Diagnostic

Sample question: Student A measures the flow rate of water coming from a tap and reports it to be (90 ± 12) millilitres per second. Student B follows a different measurement procedure and reports the flow rate to be (110 ± 1) millilitres per second. How long would it take to fill a 1 litre container?

(a) 10.0 s (b) 9.1 s (c) 11.1 s (d) 9.5 s (e) 10.6 s

Sample question: The semi-log graph below shows the natural logarithm of a population *N* of ocean water bacteria as it increases over time *t*. Which algebraic expression best describes this data?



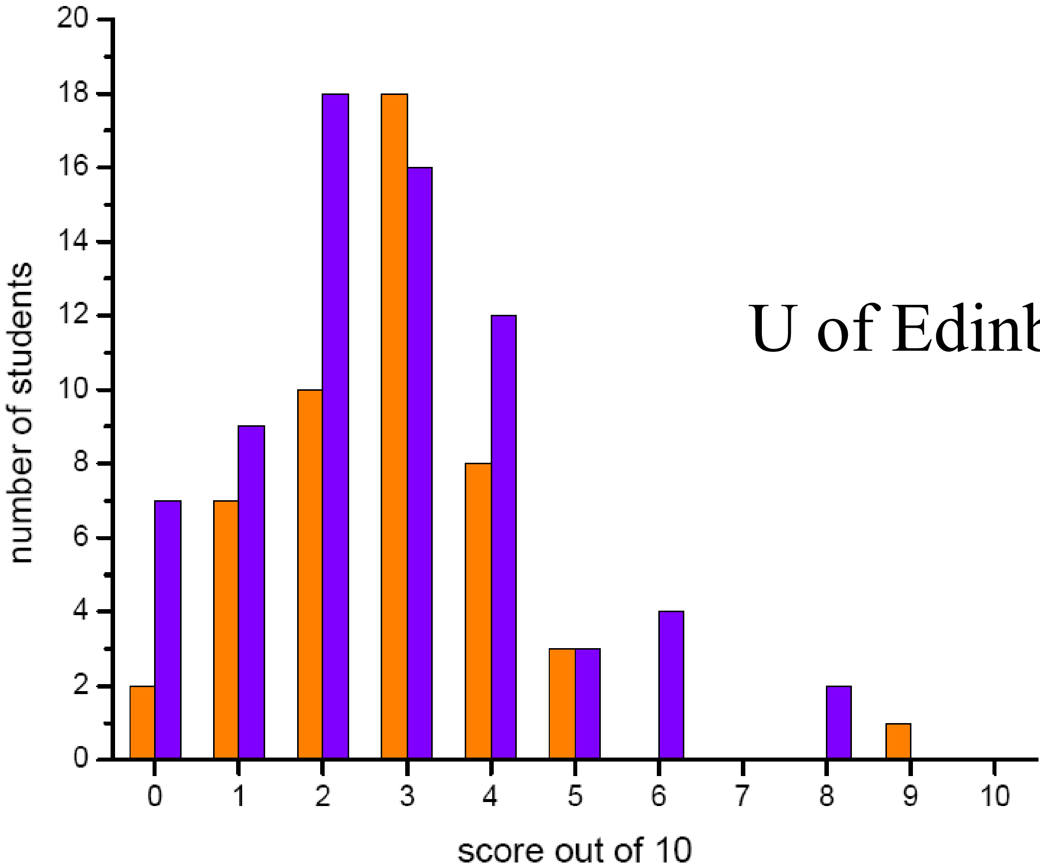
(a) $N(t) = A \cdot t + B$ {A = 2 days, B = 2.5}

(b) $N(T) = A \cdot e^{B \cdot t} + C$ {A = 1, B = 2 days^{-1}, C = 12.2}

(c) $N(T) = A \cdot e^{t/B} + C$ {A = 12.2, B = 0.5 days, C = 0}

(d) $N(T) = A \cdot e^{B \cdot t} + C$ {A = 12.2, B = 2 days, C = 0}

Pre-test results



ScienceOne (71): 2.8 ± 0.2

Phys 107/109 (49): 2.8 ± 0.2

Phys 101 (254): 2.3 ± 0.1

U of Edinburgh 1st year (249): 2.3 ± 0.1

Phys 209 (83): 4.0 ± 0.2

Phys 259 (59): 3.2 ± 0.2

Phys 409 (17): 4.1 ± 0.5

Phys 449 (17): 4.1 ± 0.5

graduate students (11): 7.5 ± 0.3

Invention Activities

The form of the activities were motivated by studies demonstrating that intuitively compelling student-centered activities can be both pedagogically tractable and provide a cognitive framework that prepares students to learn effectively[1,2].

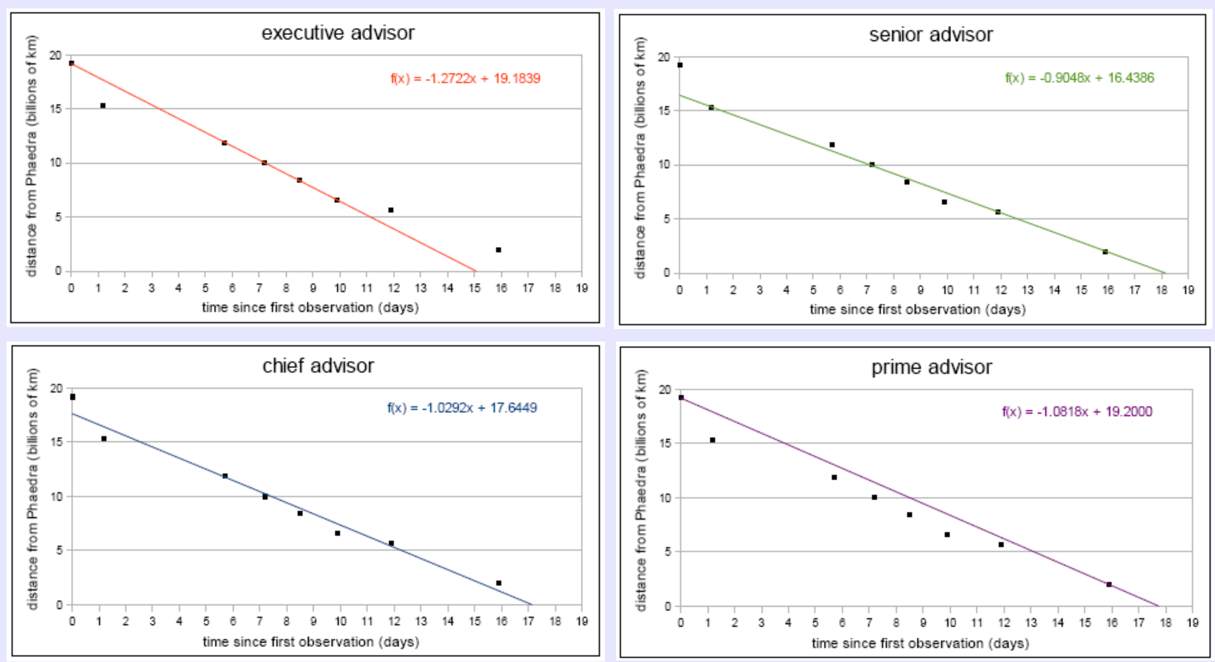
- ✗ simply telling students the expert knowledge
  - ✗ efficient because it is a shortcut
    - ✗ students do not develop integrated knowledge structures

- ✔ getting students to complete invention activities
  - ✔ students receive a set of carefully selected cases
    - ✔ invent a compact description that generalizes across the cases
    - ✔ do not need to discover the "correct" answer
  - ✔ helps students to notice important structure in the cases and to form an organizational framework that prepares them to understand conventional descriptions
  - ✔ after the activity students are told the expert knowledge

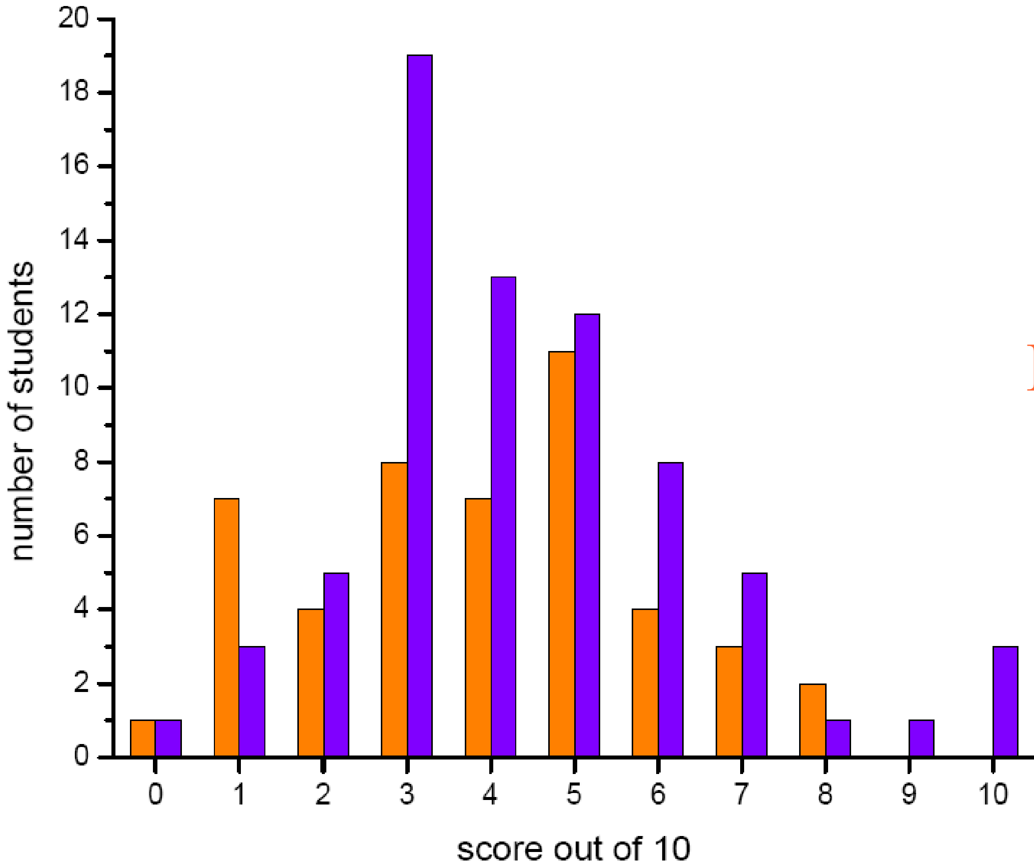
Invention Activities

Sample invention activity: (A few paragraphs of backstory is provided on the asteroid P-107 approaching planet Phaedra.) Invent a procedure for computing an "accuracy index" for each of the models given below. There is no single way to do this, but the same procedure must be used for each model, so that it is a fair comparison between the models. Write your procedure and the "accuracy index" you compute for each model using the data provided below. From that, determine which of the models provided by your advisors best describes the approach of asteroid P-107, so that you may save Phaedra from certain disaster.

distance from Phaedra (10^9 km)	time since first observation (days)
19.2	0
15.3	1.2
11.9	5.7
10.0	7.2
8.4	8.5
6.6	9.9
5.7	11.9
2.0	15.9



Post-test results
(April 2009)



ScienceOne (71): 4.4 ± 0.3

Phys 107/109 (47): 3.9 ± 0.3

General preliminary conclusions

- pre-test scores (2.8) only slightly better than chance (2.4)
  - appropriately chosen distractor options
  - universal 1st year result
- post-test scores (~4) do show improvement
  - is it significant?
  - intra-section variations exist (e.g., 3.8 ± 0.3 and 5.3 ± 0.5)
    - implementation guidance
  - intra-section similarities exist
    - persistent failure mode identification

Future directions and implications

The added benefits of **invention activities** do not always show up on routine exercises, of which sort our **physics lab diagnostic** might be. Yet strong differences become evident when students are given more expert-like tasks that include learning new related ideas and applying their knowledge to new situations[3]. Some of our "near-transfer" measurements, not presented here, are very encouraging in this regard.

The next step is to conduct more student interviews, which will help us to determine: how well our students handle the more expert-like tasks described above; whether their exist issues with our execution of the changes to the course; and if our signal was small because the **physics lab diagnostic** is too hard, meaning that a significant amount of learning may only translate into ~1 question improvement.

References

1. 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).

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

3. 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

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