Making Comparisons: A Strategy for Teaching Scientific Reasoning

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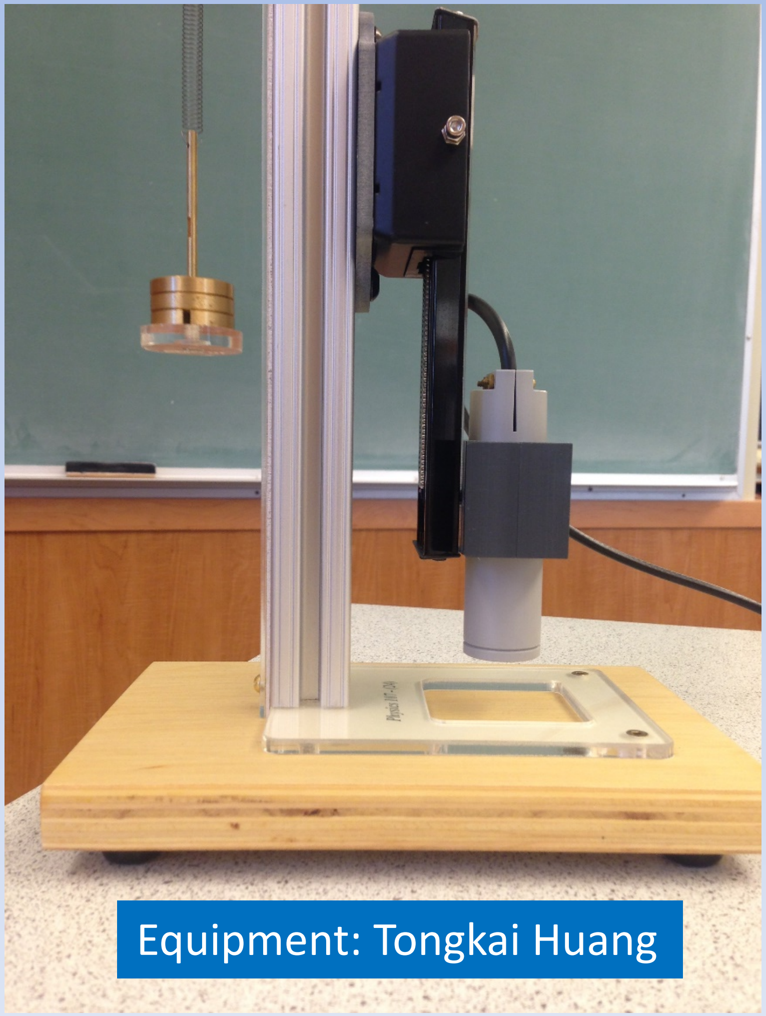


…and all of the TAs and students at UBC in 107/109/SciOne

CWSEI

What is a first year physics lab for?

Support the learning of concepts covered in lectures?
Give students a real-world experience of concepts covered in lectures?

But, there are many, often hidden, goals and tasks…

Learn to use new apparatus
Learn data handling methods
Keep a lab notebook
Making formal write-ups
Oral Presentations
Measurement uncertainty
Propagation of uncertainty
Learn to use data acquisition software
Try to debug non-functional apparatus
Figuring out how to get grades
Learning time management

Learn to use data analysis software
Learn a programming language
Learning many programming languages
Learn English
Develop scientific reasoning
Learn the 'Scientific Method'
Learn experimental design
Proper formatting of graphs and tables

Cognitive overload!

Shift goals away from support of lectures

Move away from labs as a support to learning physics concepts.

INSTEAD

- ***Develop a functional understanding of measurement uncertainty***
- ***Learn a set of broadly applicable data-handling skills***

AND A RELATED SET OF METACOGNIVE GOALS

- ***Develop expert-like habits of mind and scientific reasoning***
  - Meaningful reflection on the quality of their experimental result
  - Meaningful reflection on fit between data and model
  - Understanding the iterative nature of science
  - Develop confidence that they can do high-quality measurements

A simple tactic to attack these obstacles: Quantitative Comparison and Iteration

Students are always expected to make comparisons.

- **Scaffolded at the beginning with instructions and marks for**
  - ➢ **Plan measurements**
  - ➢ **Do measurements**
  - ➢ **Make a comparison**
  - ➢ **Reflect on comparison**
  - ➢ **Plan an improvement**

Iterate

- **Scaffolding faded over time**
- **Quantitative toolkit for comparisons built over several weeks**
- **Comparisons are never just confirming known expert results**
- **Many comparisons involve a model or assumption that fails**

Making comparisons, iterating

$t'<1$	**Possible agreement?** **Improve measurements**; reduce uncertainty, hidden disagreement?	$\chi^2<1$
$1<t'<3$	**Tension?** **Improve measurements**; reduce uncertainty	$1<\chi^2<9$
$3<t'$	**Possible disagreement?** **Improve measurements**; remove systematic error, evaluate model	$9<\chi^2$

$$t' = \frac{A - B}{\sqrt{\delta_A^2 + \delta_B^2}}$$

$$\chi_w^2 = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{y_i - f(x_i)}{\delta y_i}\right)^2$$

Research Questions

Can scaffolded cycles of comparisons and improvements result in a lasting habit-of-mind?

How long does it take?

Do these expert-like habits lead to better scientific reasoning?

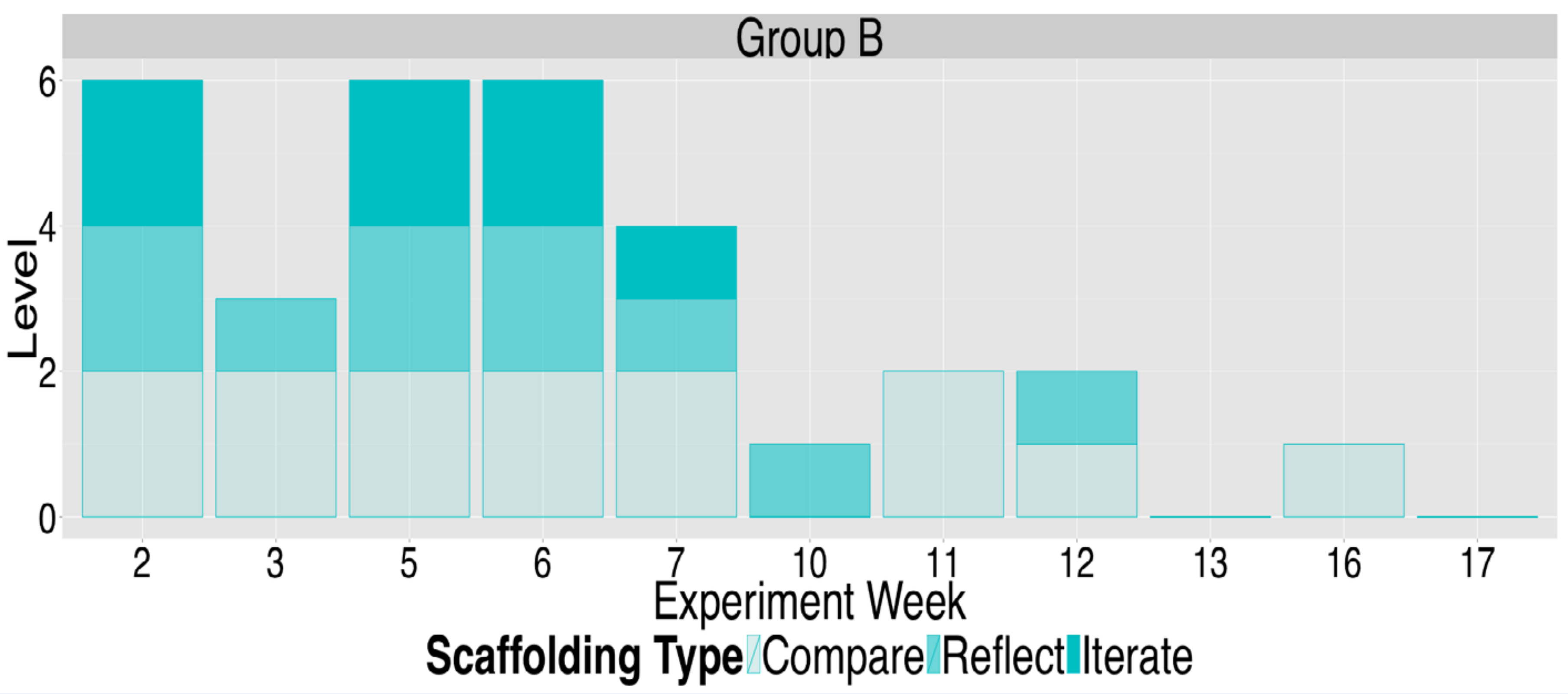
Week 2: Pendulum for Pros

Part II - 20 + 20 minutes (plan/measure + analyze/discuss)
The goal is to see if the period of a pendulum depends on the amplitude of the swing.
First, write down a plan for a high-precision measurement of the period at 10 degrees and at 20 degrees. Allow for roughly 15 minutes to do the measurements.
Compare your results at 10 and 20 degrees.
Part III - 20 + 20 minutes (plan/measure + analyze/discuss)
Based on your result above, write a plan for improving the quality of your measurements.
Discuss this plan with other groups at your table.
Do revised measurements and analysis.

Part IV - Keep repeating this cycle of comparing and improving, until you are confident that you understand whether or not there is amplitude-dependence in the period.

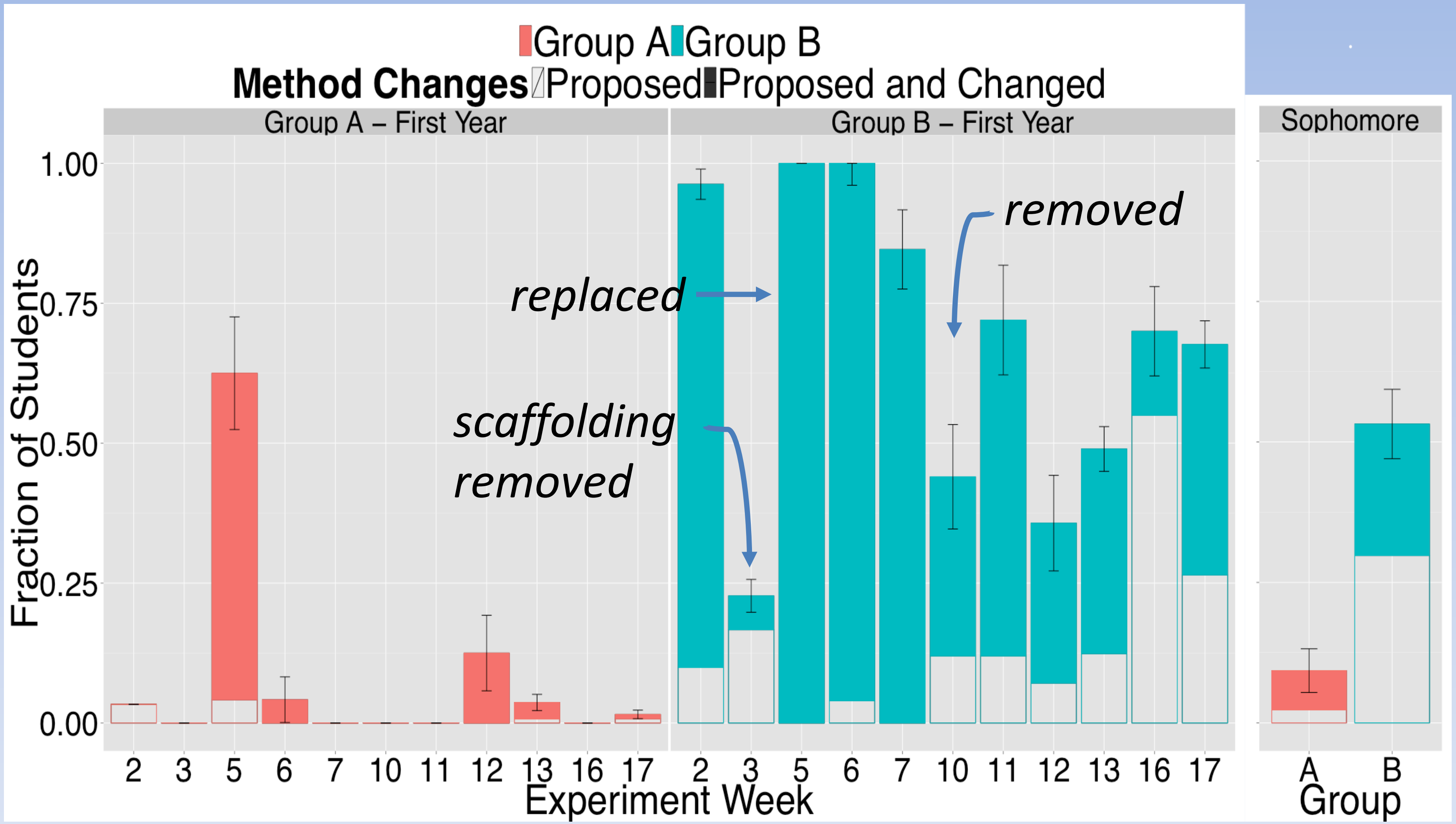
Marking Scheme
2 marks for invention activities on Uncertainty in the Mean, and Making Comparisons (something written in your lab book about what you have learned)
1 mark for first plan for measurements
3 marks for pendulum measurements at 10 and 20 degrees, and comparisons
1 mark for plan to improve measurements
3 marks for final high quality measurements and comparisons

Faded scaffolding



Student support involved instructions and/or grading scheme (so, scale of 0-2 for support of comparing, iterating, and reflecting)

Making improvements becomes a habit



Several weeks of reinforcement needed to achieve sustained improvement – and transfer to second year!

Quality of students' reflection on comparisons

Comments in students' notebooks were rated using an adaptation of Bloom's taxonomy.

Level 1 comments remarked on the outcomes of analysis (application without interpretation)

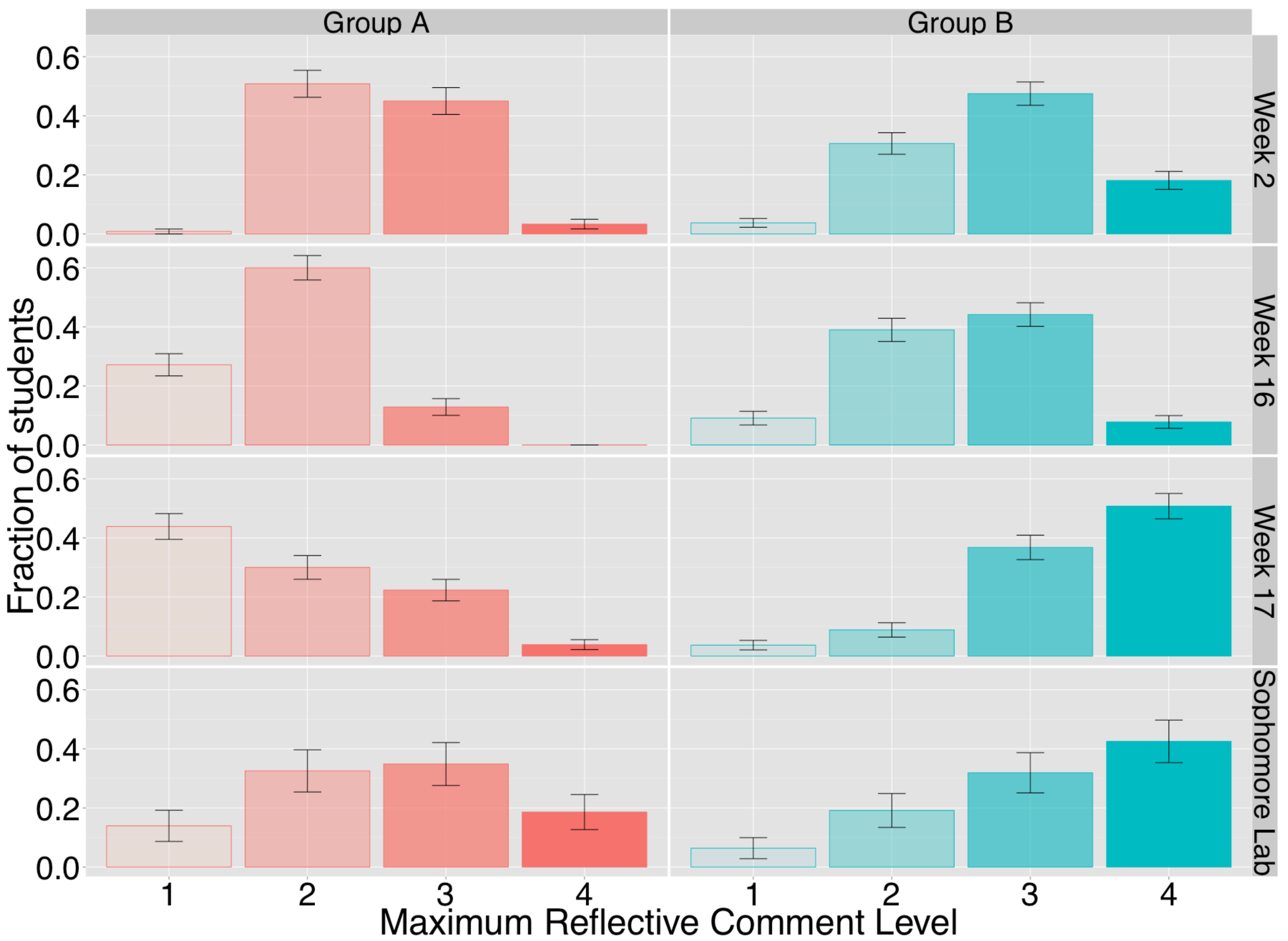
Level 2 comments analyze or interpret data

Level 3 involves synthesis of multiple ideas

Level 4 involves evaluation of the analysis in light of the synthesis

Highest level reached was recorded for each student.

Reflecting on data and results in 4 labs



scaffolded model fail

unscaffolded model succeed

unscaffolded model fail

unscaffolded model fail

[The lab] integrates everything so much more and it helps me see myself as a scientist way more than all my other classes, because those are just putting information… giving me information, rather.. It helps me actually reach in and realize, 'oh, this makes sense! I can actually do this too,' rather than just memorize a textbook."

However…. ECLASS attitude survey did not show improvement in student's expert-like thinking and attitudes.

Present study by Linda Strubbe (see poster) aims to improve student awareness of their learning and its connection to the real world.

Conclusions

Give students an environment in which they can do authentic scientific inquiry, but constrained and supported in ways that keep it productive.

Support is sustained in order to develop scientific habits (making quantitative comparisons and iterating/improving)

Support can be faded over time, leaving lasting improvements.

Students eventually take ownership of their own learning in the laboratory, with striking gains in their scientific reasoning.

Design Principles

Learn new tools at a pace that allows practice and synthesis

Experiments must be able to produce high-quality results

Experiments simple and short enough to do multiple times

No confirmatory experiments

Include experiments with unexpected, soluble problems

Support expert-like behaviours with explicit scaffolding

Careful alignment of grading and goals

Fade scaffolding over time

Near the end, practice without learning new tools

Coding reflection comments