Putting Results of *Physics Education Research* Into Practice

Teaching introductory physics with concept-based team activities

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Some history: U of T's Big Physics Course

- About 800 – 1200 students per year take calculus-based physics. 75% are biology or life-sciences majors.
- Pre 2009 structure:
  - Two 50 minute **lectures** per week in Convocation Hall
  - One 50 minute **tutorial** per week, groups of 25, one TA per group, taught in small classrooms around campus.
  - 3 hour **laboratories** every other week: "Free choice" experiments done in pairs – limited apparatus forced the labs to run independently of lectures – effectively a parallel course on experimental techniques

Pre-2009 Tutorials

- Rooms were spread around campus – it was hard to monitor what Teaching Assistants were actually doing
- We tried to get small-team activities going, but with some rooms it was difficult or impossible to rearrange the furniture to facilitate discussion with teams of 4 or 5.
- Nothing was marked in tutorials and no attendance was taken, so many students stopped attending.

Pre-2009 Laboratories: Thoughts from the students

- Some student comments from end-of-semester surveys regarding the biweekly laboratories:
  - “not always relevant to in class learning”
  - “not much relevance to what is being learned”
  - “labs are too long and quite irrelevant to the lectures”
  - “I would rather have physics labs every week rather than a 3 hour lab every other week”
  - “they are too long and confusing. the lab report is too much work for the amount of percentage that it is worth”

Some Results of Physics Education Research

Physical Review Special Topics–
Physics Education Research

- Traditional instruction (lecturing) leaves most students with **little understanding!**
- Reforms based on **active learning** can help develop conceptual understanding.
- **Connected ideas** and **association** are an important part of learning.
- Most students form connections and associations best when **interacting with their peers.**
- These interactions are most effective when they involve **conceptually based guided discovery activities.**
- The activities are most effective when they involve **real apparatus.**

The Importance of the Architecture.

[a little analogy…]

You are hungry …

How do you get something to eat in a restaurant?

The Architecture Tells You:

- Go to the counter and order food
- Pay for food
- They give you food
- Take food to a table and eat

The Architecture Tells You:

- Sit down
- A server will come
- Order food
- The server will bring food
- Eat food
- Pay

You want to learn …

How do you learn in a classroom?

The Architecture Tells You:

- Sit down
- Be quiet
- Somebody at the front of the room will lecture to you

Even if the chairs can be moved, the room has already sent the students the message. Getting small group discussion to happen is difficult if not impossible.

The Architecture Tells You:

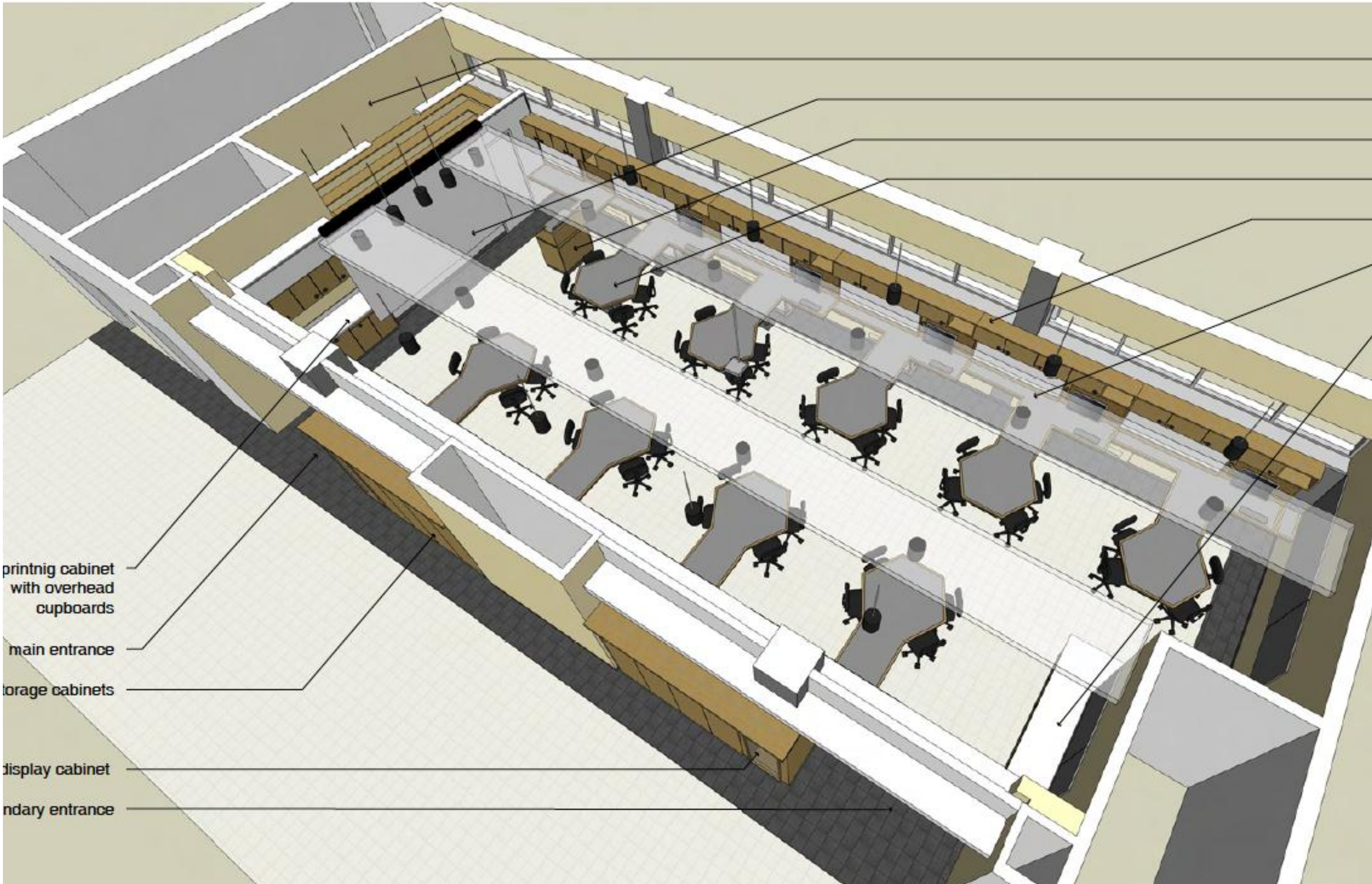
- Sit down at a “Pod”
- Talk with the other students who sit at your Pod
- Play with the apparatus that is sitting on the table.

Getting small group discussion to happen is automatic

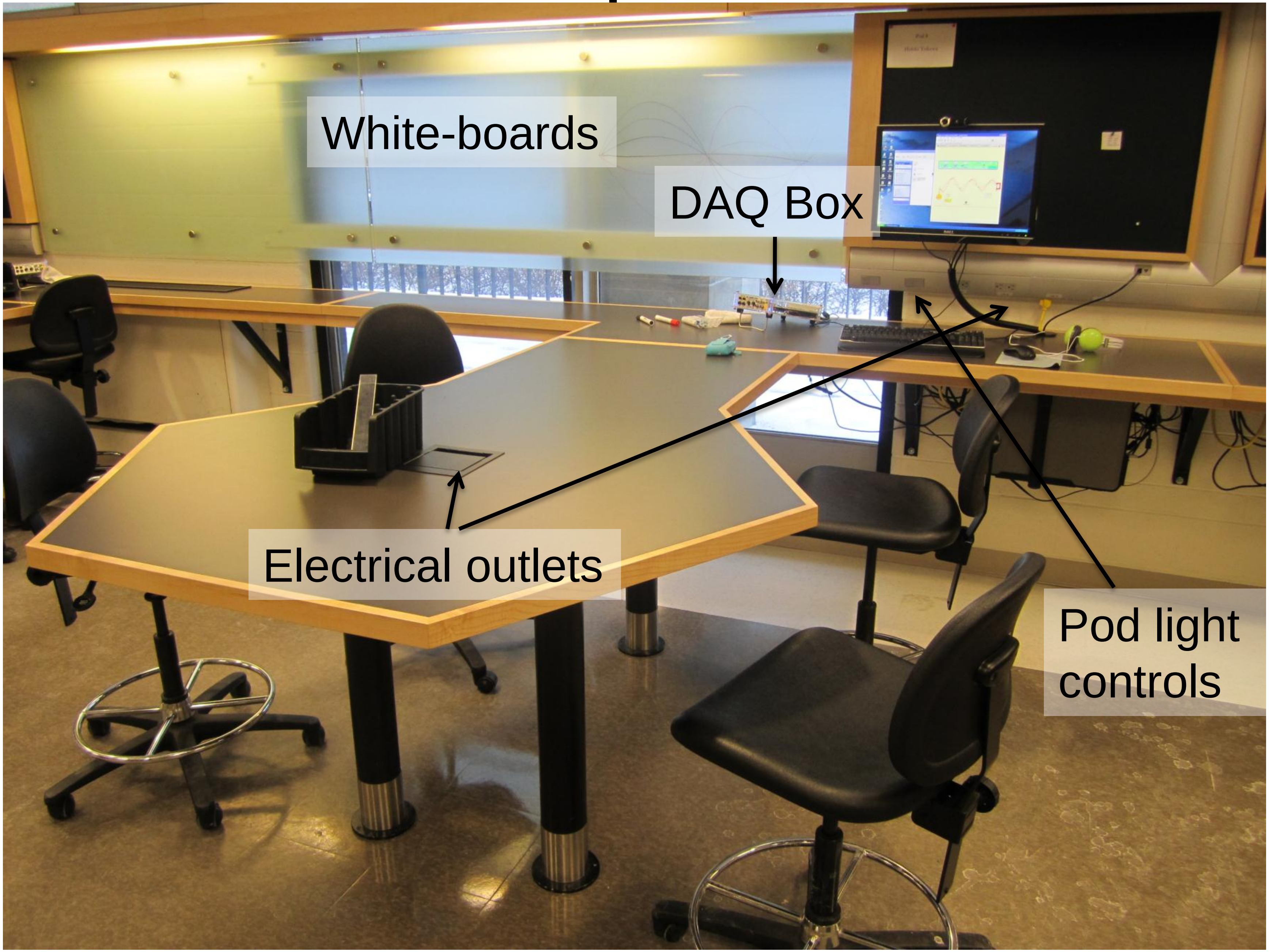
Practicals ***replace*** conventional Tutorials and Labs in 1st Year Physics

- Students work in Teams of 3 - 4
- 2 hours per week in addition to regular lectures.
- Work on conceptually based guided discovery activities
- When possible, the activities involve real apparatus or computer simulations
- Closely coupled to what is being discussed in class

Room Design
(we now have 3 rooms like this)

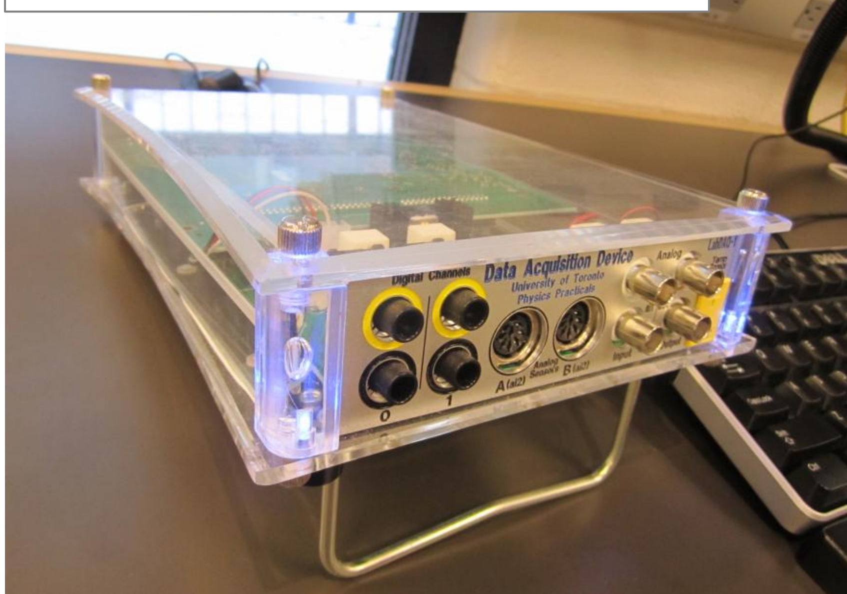


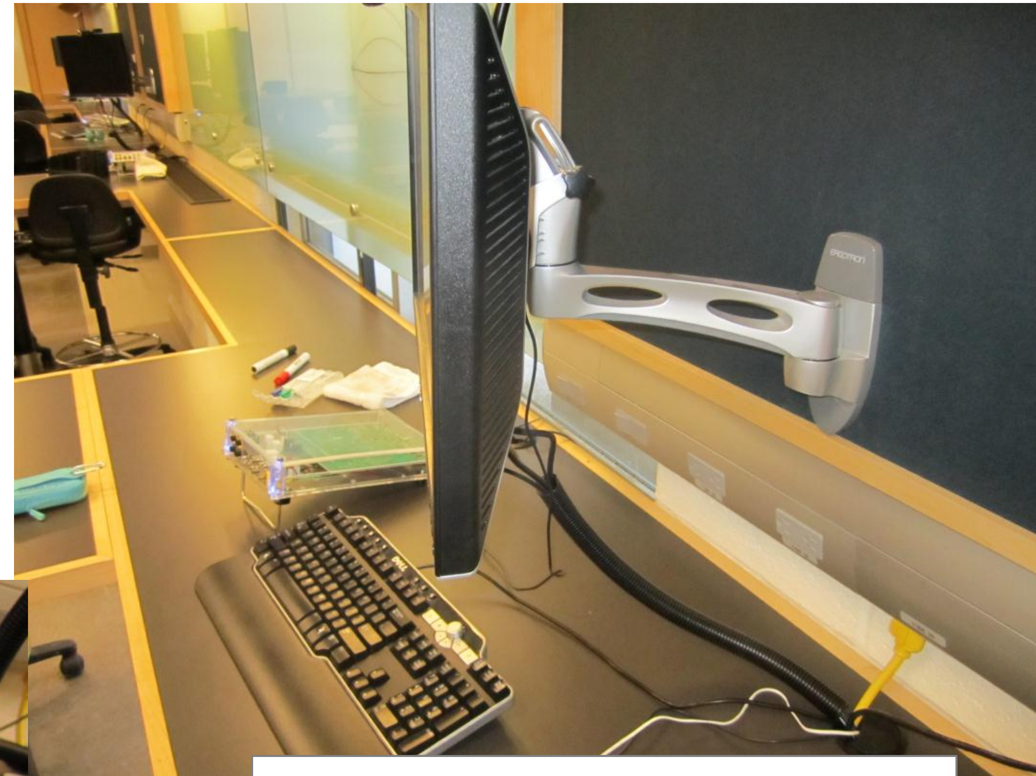
A "pod"


White-boards
DAQ Box
Electrical outlets
Pod light
controls

A "pod"

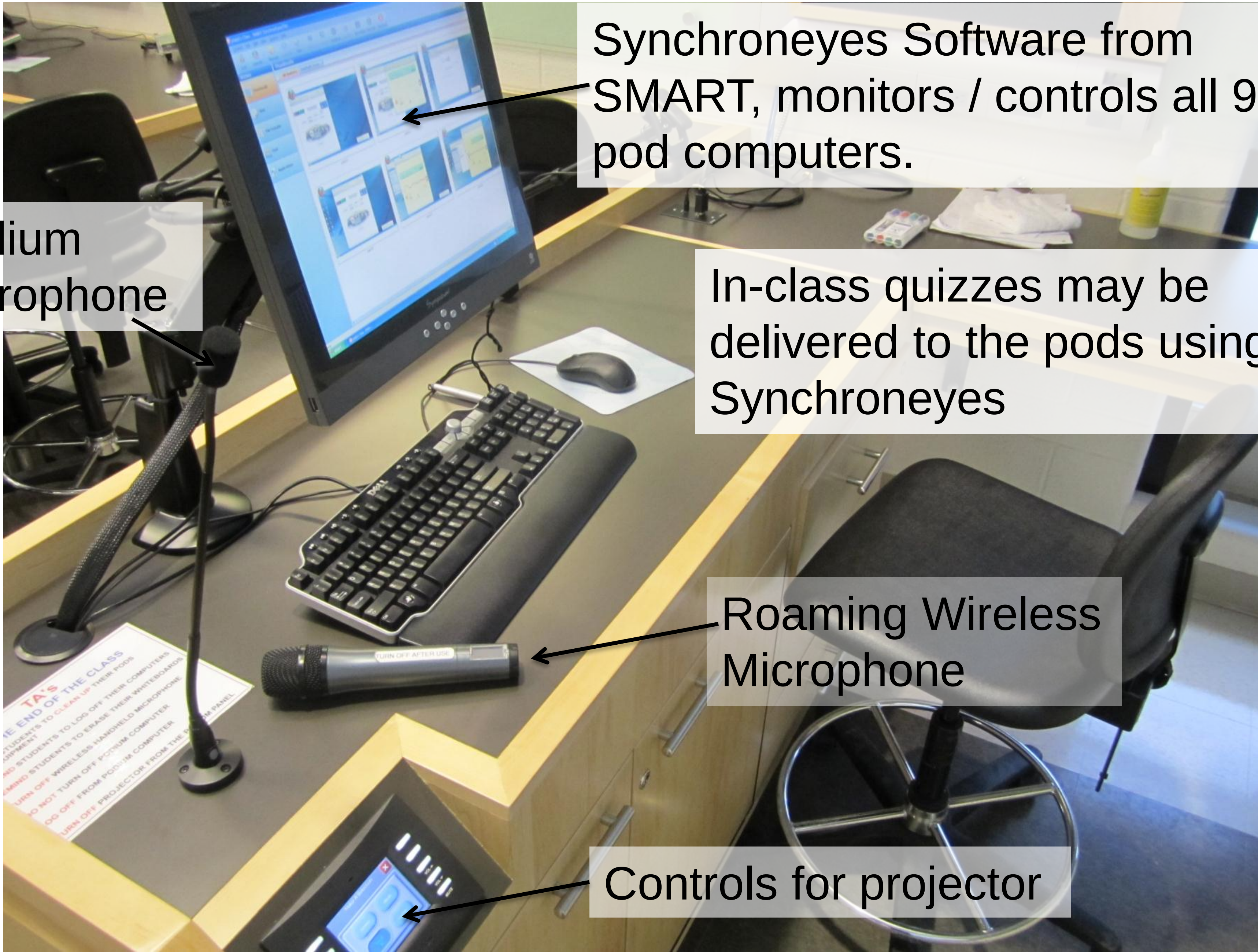
NI DAQ Board with multiple analog and digital inputs, built in-house.





Wall-mounted monitors on swivel-arms. All computer equipment may be easily pushed away when not in use.

The Front Podium



- A large set of new modules was developed during the 3 years leading up to the completion of the rooms
- ~ 200 pages of Student Guides were developed and are freely available online at http://faraday.physics.utoronto.ca/Practicals/
- Along with every Student Guide, an Instructor's Guide and an Equipment List was also created.
- Each year we can only use about 1/3 of the activities that are available – which allows us to offer different activities on a 3 year cycle

A Typical Mechanics Module **Student** Guide

Expt ***Activity 11***

Mount the motion sensor on the end of the Track closest to the wall, and use the hardware and software to repeat Part D of Activity 9. Use the switch on top of the sensor to select the narrow beam, which on some sensors is indicated by an icon of a cart. Set the angle of the sensor to 0 so it is "looking" straight down the track.

Setup the sensor so it takes 5 samples per second. Do not try to measure distances less than about 0.15 m.

A. Does this do a better job than the estimates by eye that you did in Activity 10? Explain. In particular, is the ± *error* term using this method smaller than the result for Part E of Activity 10?
B. Save your distance-time data for one of your trials to the server by using the **File** tab of the Motion Sensor vi. Use a descriptive name for the file. Since this is Module 2, Activity 11, if you have raised the track by 3 mm the file name could be: `M2A11_3mm`. Write down the name of the file and the path in the lab book.

PASCO 2.2 m tracks are used for a large number of activities.
Low friction carts are used for mechanics experiments.

A Typical Mechanics Module **Instructor** Guide

Activity 11 (30 minutes)

This extends the introduction to the Motion Sensor and associated software. It also introduces the computer system, including the polynomial fitter.

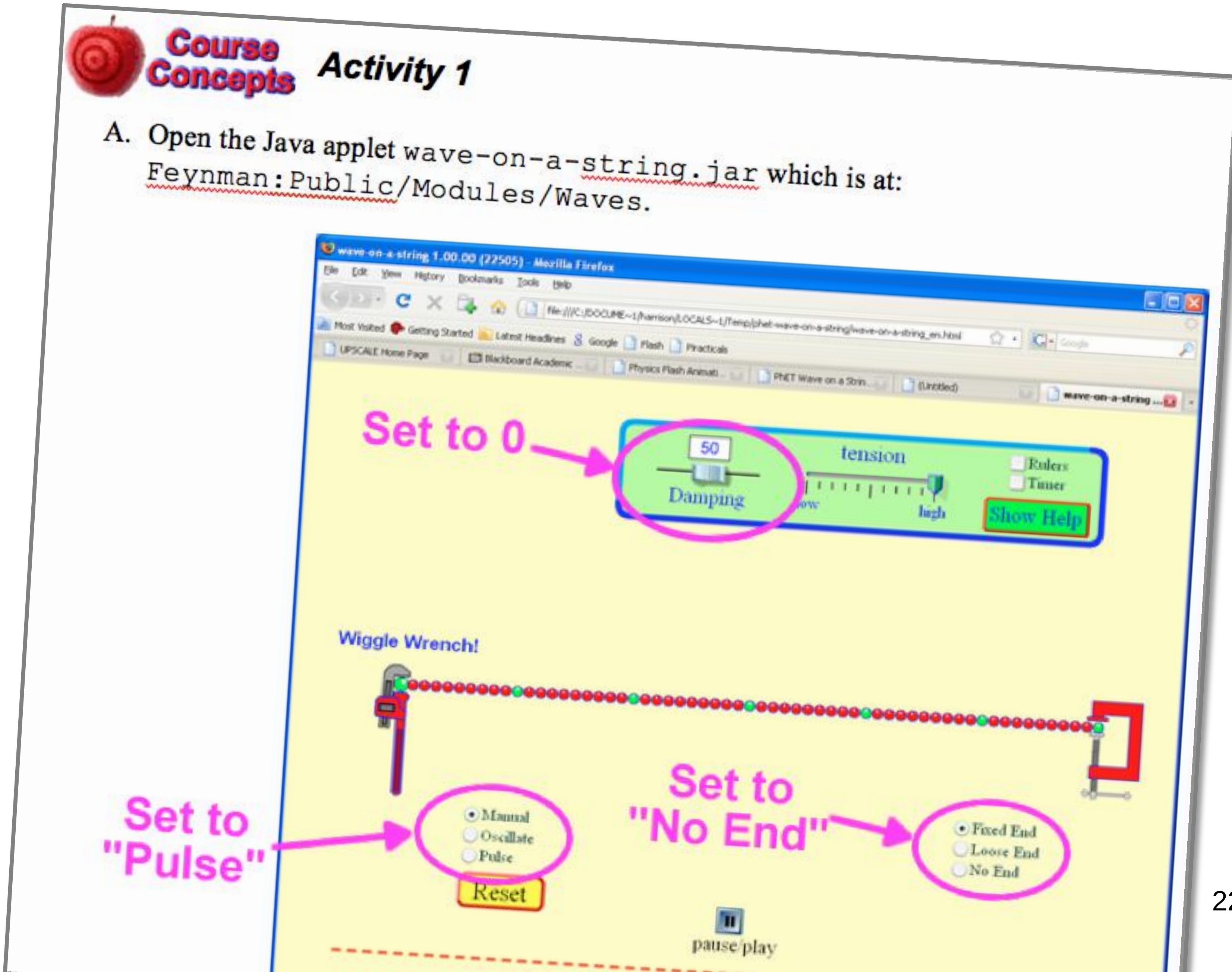
The residuals of a fit are the difference between the actual values of the dependent variable and the values returned by the fitter. When good data is fit to an appropriate model, we expect the plot of residuals to be randomly scattered around zero. When the time-distance data of the data of this Activity is fit to a second order polynomial it is common for the residual plot to instead exhibit systematic differences from zero, perhaps a “happy face” or something similar. This is probably because the track is not perfectly straight.

A Typical Mechanics Module Equipment List

Mechanics Module 2 – Equipment List and Setup

What	Qty	Activities
2.2 meter Track, Pasco ME-9452	1	9, 11, 14, 15
End Stop, Pasco ME-9808	1	9, 11, 14, 15
Collision Cart, Pasco ME-9454	1	9, 11, 15
Cart pin	1	14
6-inch string	1	14
Fan Accessory, Pasco ME-9491	1	14, 15
AA-Batteries	1 pack of 4	14, 15
Small screwdriver, for prying out batteries	1	14, 15
Motion Sensor II, Pasco CI-6742	1	10, 11, 14, 15

Student Guide examples: Working with Animations



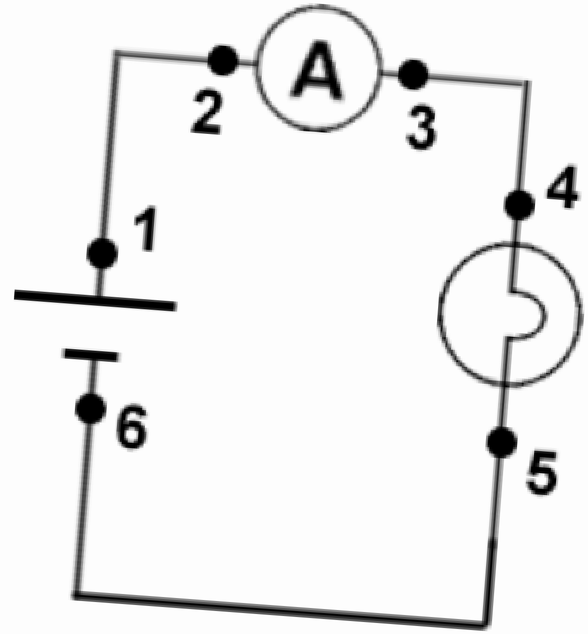
Many students bring their laptops.

Student Guide examples: Working with Circuits

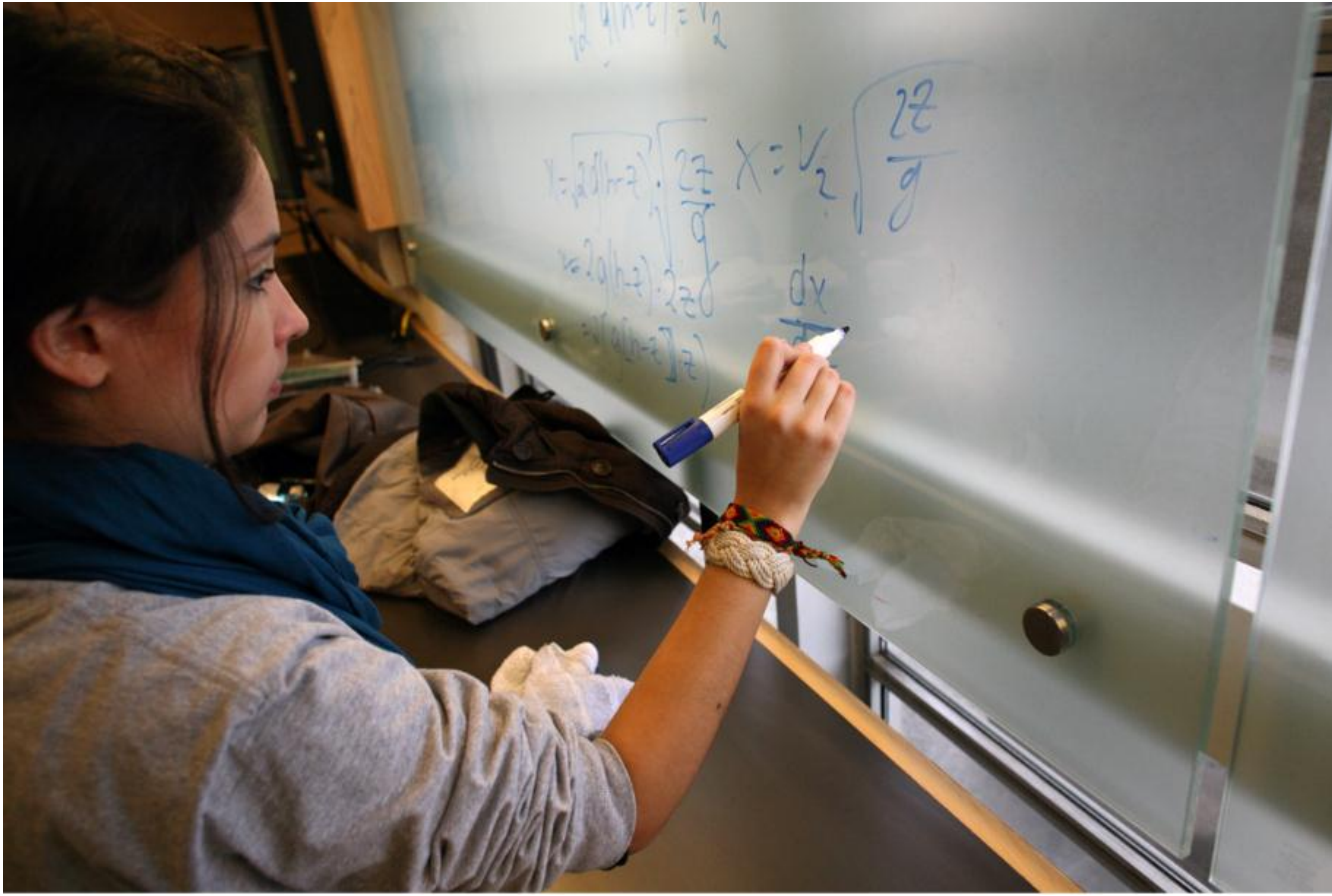
Course Concepts

Activity 7

Rewire the circuit that lights the light bulb with the ammeter in the circuit again. In the circuit diagram to the right we have indicated a number of points in the circuit. Use the voltmeter to measure the voltage difference between **1** and **2**, **2** and **3**, **1** and **3**, **4** and **5**, etc. If the meter reads a very small voltage difference between two points, you should decrease the scale of the reading by rotating the upper knob: when the scale is too small the meter will read **-1**; in this case increase the scale of the reading.



Do you see a pattern? What is the voltage "drop" across the light bulb? What about across the ammeter? One of the wires? Summarise your findings. Can you explain them? Why did we use the word "drop" above?



Working through problems on the whiteboards.

Teams share the work, …and share the mark!

- Each team has a notebook, which never leaves the classroom.
- Teams are scrambled once per semester.
- At the start of each session, teams choose a **Note-taker** and **Facilitator**.
- The roles of Note-taker and Facilitator must change person every session.
- In the first semester there is a teamwork module to show students how to make teamwork more effective and fruitful

A Typical Session

- First 30-40 minutes: Questions from the class, In-class computer-quiz questions, discussing Masteringphysics problems, announcements (problem set reminders, etc.)
- Final 70-80 minutes: working on the activities of the week.

Practicals are lead by graduate student Teaching Assistants (T.A.s)

- Each room has 9 pods, so up to 36 students in a practical.
- Two T.A.s are present in the room.
- T.A.s use a Socratic model … Lecturing to the entire room is discouraged / forbidden.
- Experienced and Inexperienced T.A.s are paired.

TA Training

- TAs attend mandatory paid weekly meetings in which we discuss the upcoming activities, teaching issues, etc.
- There is also 3 hours of mandatory training at the beginning of the course.
- All the extra training was possible because we reduced the number of hours spent marking.
- TAs mark notebooks on the 4-point integer scale.
- Only a selection (1 in 5) of activities are actually marked, chosen at random twice per semester.

Some other successful changes we have implemented since 2004..

- Students are assigned online homework using www.MasteringPHYSICS.com
- Tutorials guide students through the toughest topics in physics with self-paced tutorials that provide individualized coaching
- These assignable tutorials are designed to coach students with hints and feedback specific to their individual misconceptions
- Students spend 2 to 4 hours per week on these, and marking is done automatically by the software

Some other successful changes we have implemented since 2004..

- During large lectures, multiple choice discussion questions are asked using Personal Response Systems, or “clickers”
- These questions are usually conceptual, requiring no detailed calculations
- Discussion with neighbours is encouraged before voting
- Student identification is registered online with the clicker
- Marks are assigned based on participation with a slight bonus for getting the correct answer

The “Clickers”

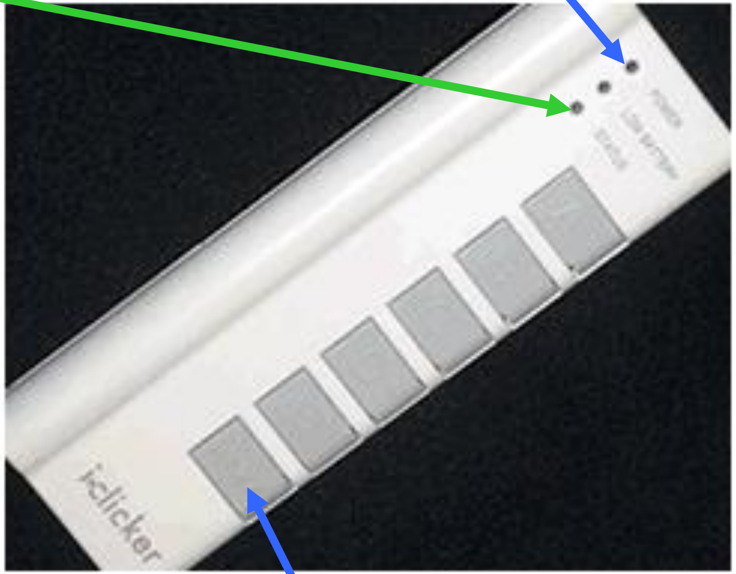
Status Light

When I start asking clicker questions:

• Will flash green when your response is registered

• Will flash red if your response is not registered

Power Light



On/Off Switch

Please turn on your clicker now

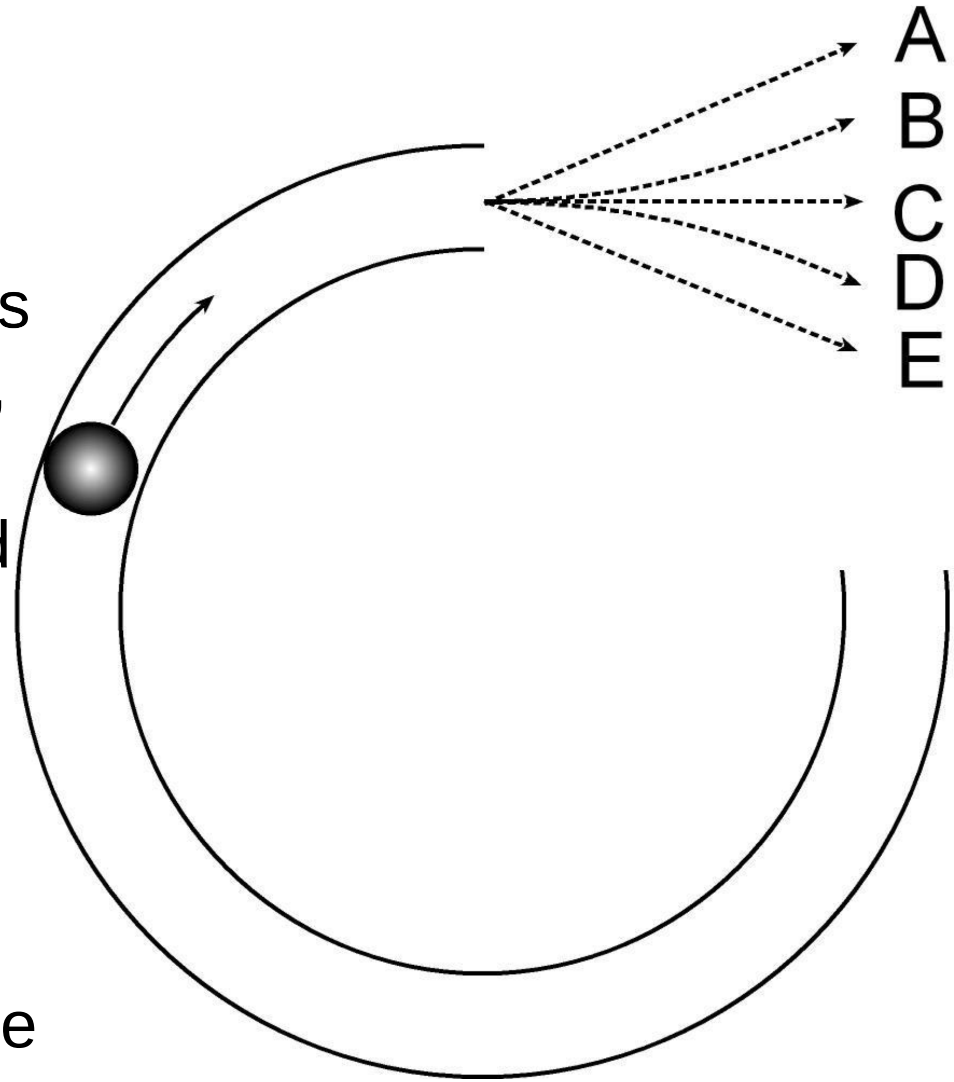
Quick Audience Survey . . .

What is the largest class you have taught?

A. Fewer than 50 students
B. 50 students
C. 100 students
D. 200 students
E. More than 200 students

A typical clicker question…

A ball rolls along a frictionless track on a horizontal table, as seen from above in the figure. The track is curved in ¾ of a circle. The ball rolls clockwise around this track and then emerges onto the flat, frictionless table. Which dashed line most closely represents the path of the ball when it emerges from the track?



Two balls are launched along a pair of tracks with equal velocities, as shown. Both balls reach the end of the track. *Predict*: Which ball will reach the end of the track first?

- A
- B
- C: They will reach the end of the track at the same time

Explanation: *Why* does ball B reach the end of the track first?

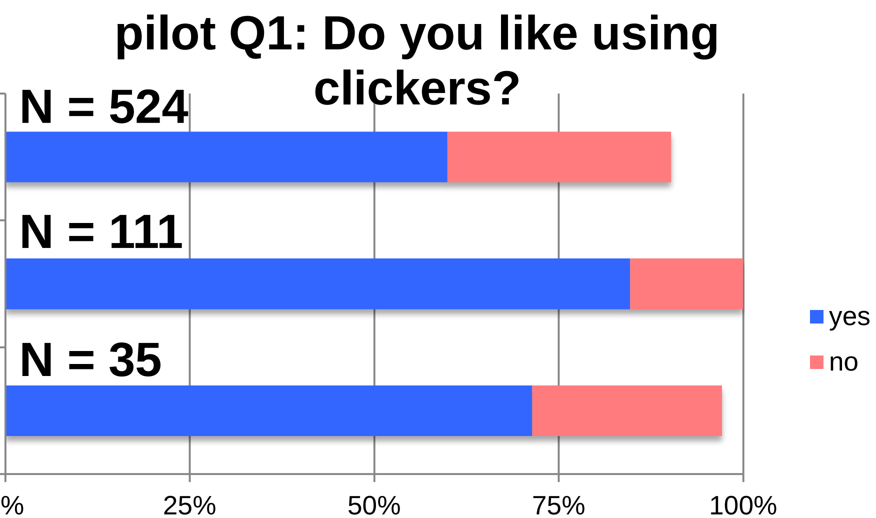
A. Ball B is always traveling faster than ball A, so it reaches the end of the track first.
B. Balls A and B start and end with the same speed. But while ball B is on the lower part, it is going faster than ball A because gravity has sped it up. Its *average* speed is greater, so it gets there first.
C. Ball B travels a shorter distance than ball A.
D. Ball B travels a longer distance, but is pulled faster by an extra force we cannot know about.
E. The observation is flawed – ball B should not reach the end first.

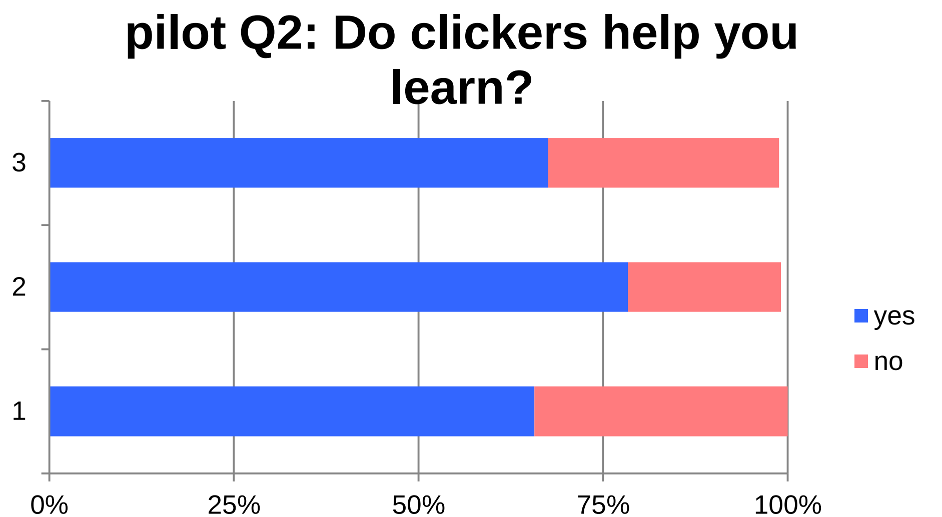
Advantages of Using Clickers

- Student engagement
- Instructor gets feedback on student understanding
- Students get feedback about their understanding
- Helps stimulate in-class discussion and peer instruction
- Anonymity of clickers
- Engages even the quieter students
- Students think clicker votes are fun
- Encourages lecture attendance

Student Survey about clickers

- 3 courses of different sizes:





Student Survey about Practicals

- We have analyzed 3 semesters of end-of-semester survey data from labs and tutorials before 2009
- We have analyzed 3 semesters of end-of-semester survey data from Practicals after 2009
- Multiple choice responses for similar questions significantly more positive than for the 3 semesters before Practicals.
- Certainly when I stroll through the practicals and speak to students at pods, they seem energized, enthusiastic and often immersed in discussions about the material.

Recent Student Survey Comments

- Some student comments from end-of-semester surveys done in practicals:
  - “practicals are the #1 way to learn”
  - “some practicals covered the materials that haven't been covered in lecture yet”
  - “I thought overall the practicals were set up well. Both Vijay and Eric were outstanding TAs; I'm not that great at physics nor do I really enjoy it but they made it interesting plus they were incredibly helpful. I learnt a lot more from them than I did in class”
  - “the practicals should involve more problem solving questions and student question help.”
  - “the marking scheme is a little strange - no part marks and out of 4? in addition some of the practical questions are vague though some purposefully. One thing that's completely unacceptable is spending $10 on the lab manual only to discover that the online manual has some different questions - the printed manual should be up to date upon printing”

What do the TAs think?

- 33 graduate student TAs responded to an anonymous paper survey distributed in December 2010.
- When asked to respond to *“Overall, the Practicals provided a good learning experience for the students.”* **16 said “Strongly Agree”, 16 said “Agree”**, 1 said “Neutral”, 0 disagreed or strongly disagreed.
- When asked to respond to *“Overall, I enjoyed working with students in the Practicals.”*, **25 said “Strongly Agree”**, 6 said “Somewhat agree”, 0 were neutral, 1 said “Somewhat disagree”, and 0 strongly disagreed.

The $2 million question: Are the students learning more?

- We are comparing same or similar multiple choice test and exam questions given in the years with labs and tutorials (< 2009) and in the years with practicals (> 2009).
- This is difficult to do; test questions are very rarely repeated, as students may have access and may try memorizing past questions.

Fall 2006 Test 1 (labs + tutorials)

Very Preliminary Data

Question 8

A cyclist's average metabolic rate during a workout is 500 W. If the cyclist wishes to expend at least 300 kcal (1 kcal = 4186 J) of energy, how long must the cyclist exercise at this rate?

(A) 0.6 min (B) 3.6 min (C) 36.0 min (D) 41.9 min

736 students wrote the test, and the average on this question was 73.4%, with a standard deviation of 1.7% between the two versions. [with 3 distractors]

Fall 2010 Final Exam (practicals)

7. A cyclist's average metabolic rate during a workout is 500 W. The cyclist wishes to expend at least 300 kcal of energy. The time, in **minutes**, that the cyclist must exercise at this rate is closest to:

(A) 0.6 (B) 3.6 (C) 36 (D) 42 (E) 2500

650 students wrote the exam, and the average on this question was 74.5%, with a standard deviation of 0.3% between the two versions. [with 4 distractors]

Result: Insignificant increase (+0.6 σ)

Thank you!

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MP129-A

University of Toronto,
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U of T President David Naylor interacting with students in one of our first-year physics practicals.