Experiences with running an experimental physics lab for students.

Craig McNeile\textsuperscript{1}

craig.mcneile@plymouth.ac.uk

\textsuperscript{1}University of Plymouth, Centre for Mathematical Sciences

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Physics on the foundation year at the University of Plymouth.
The experimental labs in this service module.
Replacing some experiments with simulations.
Replacing more experiments with a mobile phone mini-project.
One slide on group work.

I am a theoretical particle physicist. My research area is in lattice QCD. I use High Performance Computing to solve the equations of QCD.

There is lot of pressure from the management to reduce the “cost” of introductory experimental labs.

It is not clear how useful the physical experiments on introductory modules are for the students.
Foundation year is for mature students and/or students who didn’t get good enough grades at A-level to enter first year engineering degrees. There are also mathematics modules, which start at just above GCSE level.

This type of program is important for (economic) diversity.

I am teaching a 20 credit physics module to (Civil, Electrical, Robotics, and Mechanical ) Engineers.

Essentially the content is A level physics. (There is a second module on Physics in the second semester.)

Roughly 120 students on the module.

Exam 40 %, Experimental labs 30 %, Weekly online Coursework 30 % (Maple TA.)
How the labs used to be run

- Two experiments are run in a two hour period.
- Students used to complete 8 experiments in the semester.
- The students work in groups of 4 (when everyone shows up).
- The lab will hold 32 students and is normally used for electronics / robotics group work.
- I now work with one senior lab technician.
- Experiments are sometimes done before the background is covered in the lectures. (We made one introductory video).
The results recorded in “highly” structured worksheets, which have been reused for many years. The students typically need to include the correct units with measurements and draw graphs.

For certain values of the length of the string and wavelength, there are different possible patterns called “modes”. Some examples are shown below:

![Standing wave pattern diagram]

When looking at a standing wave, you are actually seeing the superposition of two waves (blue and red in the figure above).

LENGTH AND WAVELENGTH

1. Start with the lightest weight of mass 50 g. This fixes the tension in the string and hence the wavelength.

2. Switch on the vibration source and vary the length of the string. You should observe that standing waves stabilise in the string for certain values of the distance (L) between the Pulley and the Vibrator.

3. Measure the value of L, the distance between the Pulley and Vibrator, for a few different modes. Hence, compute the wavelength (λ) in m for each measured harmonic. Record the results in the table below.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>L m</th>
<th>λ m</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Explain which harmonic do you expect to give the most accurate estimate of the wavelength?
Use of PHET simulations

https://phet.colorado.edu/en/

Founded in 2002 by Nobel Laureate Carl Wieman, the PhET Interactive Simulations project at the University of Colorado Boulder creates free interactive math and science simulations. PhET sims are based on extensive education research.

- Three years ago, I replaced two physical experiments with PHET simulations.
- The students still filled in highly structured worksheets.

Some reasons

- learning skills, (accurate use and manipulation of instruments, inquiry skills, order and communication, critical thinking, and problem solving),
- attitudes (curiosity, openness, reality, objectivity, accuracy, and cooperation in teamwork).
- concepts (concrete representation of concepts)
- Cultural. Physics is based on experiments.
The executive summary is that I can't use the papers below to defend the experimental labs.

One view is that the students should do experiments with very little guidance, so that they discover physical principles by themselves. If You Want to Teach Physics Lab Right, Skip the Manual (Rhett Allain, blog post).


- Cognitive load theory (Book by John Sweller, Paul Ayres, Slava Kalyuga)
  - It is better to start with worked problems, then with problems with very little structure.
  - Expert reversal effect.

Start with highly structured experiments and then reduce the scaffolding
Mobile Phone projects

This year I replaced two experiments with a mobile phone mini-project. (Many people have used these for teaching) There are a couple of Apps that allow easy access to sensors:

- Accelerometer
- Sound level
- Light level

https://phyphox.org/ Phyphox from from RWTH Aachen University in Germany

https://sciencejournal.withgoogle.com/ Google science journal.

There was a two page limit, some suggestions, and a basic marking scheme. The idea was for the students to explore outside the lab.
Phyphox

There is an insecure way to connect the App to the web browser.
I was very happy with what the students submitted. I didn’t build in any feedback, but I didn’t get any complaints. I was worried that they would think I was asking too much.

**Inverse square law**  sound

**Accelerometers**  The acceleration of a lift and dropping phones.

**Sound Db**

For next year:

- How to calibrate the sensors in the mobile phones?
- I need to teach them how to write scientific conclusions. For example, a null result is OK. Next year, I am going to ban the phrase ”Human error.”
Group work

- We are asked to teach students to work in groups, but often we just put them in groups and then say “job done.”
- In the lab manual I briefly mention group dynamics. For example, Bruce Tuckman’s ideas on how a group: Forming, Storming, Norming, and Performing.

Following ideas by Knowles on learning contracts, I introduced a group contract.

Group organization Write a few sentences about how you organized your group to complete the laboratory sessions (2 marks.)

Experimental measurements Write a few sentences about what generic lessons you have learned about making experimental measurements in a physics or engineering laboratory (2 marks.)

Additional rules of the group Please add additional rules here (1 mark.)
Conclusions

- In principle experiments are an excellent way to do active learning in physics.
- Unfortunately, experimental labs are expensive to run both in space and staff costs. (It has been recently approved, that the engineering school will get a new building, which should have more innovative spaces.)
- Some of the students on the foundation year need more support, than say students in the final year.
- As the University gets better with analytics, it will be interesting to compare the degree results of students from the foundation year, with those from direct entry.

*The role of deliberate practice in the acquisition of expert performance.* KA Ericsson, RT Krampe, C Tesch-Rmer - *Psychological review*, 1993

10,000 hours of practice to become an expert.