Barriers to progress in physics in secondary and tertiary education

Andy Ross
School of Chemical and Physical Sciences
Victoria University of Wellington

As educators, we're employed both for our supreme knowledge of science and our incredible skills in teaching it to learners of all ages. But sometimes it is frustratingly difficult to help our students progress at the rate we (or the government) expect. Often this is because there are hidden barriers to learning which are blocking the learning process. These come in many flavours, from behavioural to social and, of course, academic.

In this year's teachers' day presentation we discussed several areas which are easily overlooked in our frantic drive to deliver the curriculum.

Estimation skills

Estimating is a core skill in the physical sciences. Most of us are confident to scope out an unknown problem with boundary conditions, apply some mathematical and physical knowledge and laws, draw upon our life experience and general knowledge and combine these to compute ball-park estimates for answers. We also, of course, use the same skills in querying an answer to check that it's sensible.

It's clear that many prerequisite skills are needed to perform estimations successfully and these are largely based on exposure and experience. Essential numeracy skills include confidence not only in the basic operations of mathematics but also knowing when to apply them - do we use division or multiplication for example? Whilst we can use the internet to find solutions or gather raw data for an estimation we don't always have the luxury of research resources and in those situations we need to draw upon life experience and our ability to visualise and quantify. We saw this in the sample exercise where we had to roughly estimate the number of blades of grass on a football pitch; in this problem we used our experience of sitting on grass to come up with an approximation of the number of blades that we might find in one square centremetre of turf. This comes from experience. If we had to estimate how many ants are crawling around in a square metre of rainforest floor in the Amazon would any of us have the personal knowledge to draw upon and make a realistic answer? Probably not. We have to be realistic in our expectations of learners' prior knowledge.

We also discussed how in group work involving estimation students enrich the process by bringing a wider range of personal experience and background skills but face the problem of reaching a consensus decision in both a democratic and scientifically valid way. Overlaying the psychsocial issues of group agreement adds another layer of complication to classwork on estimation. As teachers we try to moderate and nurture group work, but from our personal experience in staff meetings we all know that some people will run their mouth and dominate the conversation and this often leads to decision making which is not optimal. You know what we mean…

At the end of the calculation component of estimation we expect students to present an answer and to critically verify (which requires, again, an experiential knowledge base) their conclusions. If we don't encourage this final part of the process we're not encouraging reflection and the incremental process of drawing upon prior knowledge and cross-referencing with experience. We usually do this verifying step instinctively, because of our age and skills sets.

For example, if we had crunched the numbers and concluded that the football field had a total of 1000 blades of grass we'd intuitively know that our answer was bonkers. Being confident with number magnitudes we'd also think that 100,000 or even a million was too small. Our advantage over young learners is that we have the experience to comprehend and possibly visualise orders of magnitudes of quantities. Many of our students don't, so it falls upon us to help them reflect on answers and try to develop associations with number, quantity and real-life problems.

So there are many potential blockers and barriers to successfully completing an estimation task. But let's add to this by including the love of absolute answers in educational tasks. Students like to provide a definitive answer. As teachers we like them too because it gives us an assessment point: it's either right or wrong.

However, estimations fall in to the category of creating slightly nebulous answers. The football field glass problem will, of course, generate answers that can vary by several orders of magnitude, depending on students' assumptions about the density of grass. We therefore have to provide a range of answers in estimation problems to guide our learners into not expecting numerical perfection (which is what we usually demand, right?) yet make it clear that there are boundaries in estimation which are set by the constraints of the physical world.. There is naturally wooliness in the solutions that students give and in those that we provide. And many learners, and possibly teachers, may be uncomfortable with that as it's possibly incongruous with the definitive answer culture of secondary science. It's a subtle aspect of estimation skills but it does contradict the normal expectations of mathematical calculations in schools.

Some of us may argue that estimation skills are probably not given due priority across the school curriculum. We blame the maths department (nothing changes!) for not helping our students develop these skills, perhaps for not placing enough emphasis on tackling open-ended questions or building experience in questioning the orders of magnitude of answers to real-world problems. We rage at the NZQA for not giving estimation due importance in the science curriculum and we quietly grumble about our principals for not giving us the personal freedom to take the time needed to teach estimation because we're under so much pressure to cover the curriculum…

So it it actually practical to build estimation skills in to our already packed programme? How can we help our students develop estimation skills, from year 9 through to 2nd year undergraduate? Obviously, we need to make time and actively plan for it… Five minute starter activities, or plenaries, perhaps are obvious slots in our teaching. Simple activities such as asking students to estimate the numbers of sweets in a jar, or the number of chairs in the school as a quick-fire warm up will get students thinking and using basic numeracy and general knowledge in a context which they are familiar with and without slowing down teaching too much. Although we can't just box tick the practising of estimation skills. The task doesn't end with the students presenting their answer. We need to include review of their answers and teasing out their justification as, afterall, our role as experienced and confident scientific estimators, is to scaffold learning by sharing our approach and guiding the learning. We model our method, our maths, our checks and our justification and showcase the generic skills that we apply.

Some colleagues in the physics teacher meeting in Whanganui decided that developing estimation skills would make a good professional development task for 2020, which was fanstastic. But it's not just in secondary settings where we need to work on estimation: We're noticing gaps in estimation skills, both in problem solving and in answer checking, in our undergraduate students and hypothesise that this reflects a lack of practise in this area in previous settings. And yes, this weakness probably goes back to their primary days too… so it's something that here a VUW we're going to have to work on too.

At the end of this document we've generated some estimation starter questions because this is a dauntingly huge area for resource creation. We suggest that any sustainable approach to teaching estimation skills is best done as a collaborative project within science teams and one, perhaps, where some measureable indicators of impact might be worth generating as a group activity. As always, we'd love to hear your ideas and feedback.

Other ways that estimation can be built in to physics teaching may be through inclusion in homework activities or in encouraging student-generated questions. Informally questions on estimation can be created just by discussing a picture, as we did with the football field.

Finally, we also believe that any cohesive approach to teaching estimation skills in the science classroom would also benefit from collaboration with the maths team. If we're finding that students are weak in working with exponents, or in rounding to simplify basic arithmetic, then it's clear that the mathematics team could use this feedback and do something about it.

We'll revisit this aspect of learning barriers in physics next year and look forward to hearing your case studies or observations.

Literacy and physics

You read fluently and consequently have high levels of proficiency in reading comprehension, inference and literacy deduction. But do your students?

Look at a physics textbook for any of your year groups and you'll see a range of writing styles, from vaguely informal to serious and formal academic, yet are we matching our resources to the literacy abilities of our classes? Typically we can have students in mixed ability classes with reading ages spanning several curriculum levels. There is no chronological age-reading age correlation because, as we all know, there is a bell curve of literacy ability. *Yet how well do we match our written physics tasks to literacy abilities?*

In the teachers' day presentation we looked at a couple of examples of printed physics assessment and many of us were shocked, on reflection, when we analysed our go-to physics questions resources from a readability perspective. We focus on developing our students' physics skills yet we wrap them up and deliver them via literacy – and numeracy, of course. Many questions are verbose, when we reflect on them. In some, the science is almost lost in a kerfuffle of reading comprehension. And whilst, as competent adult readers, we unconsciously decipher written physics questions are we expecting our students to be able to do the same? At times, we are possibly setting our students with weaker literacy skills up for failure by cloaking the material that we're assessing them on, or supporting their learning with, within a cloud of overly complex language and some downright dodgy presentation?

It is very easy for us to grab a text-based learning resource and put it in front of students, expecting them to answer the physics (or chemistry or biology) tasks, but if we look at the material through the eyes of a student with under-developed literacy skills the planned learning task immediately becomes the secondary goal – the student's primary goal is to work out what on earth they are being asked to do. The same barrier, of course, applies to students with atypical approaches to learning, to those with specific learning difficulties or to students with English as an additional language.

We are expecting our students to:

- have a specific level of competency in literacy skills
- to be able to convert accurately between the sometimes informal language of teaching and the often formal words found in textbook problems
- recall the meaning and broad concepts associated with scientific terminology
- to distinguish between the everyday use of some words and their specific meaning in STEM contexts
- to have appropriately developed levels of inference and deduction.

Decoding of problems in physics becomes even more complicated if they are presented orally, because we also then need to overlay listening skills and the idiosyncratic language choices of the teacher.

And we're not even going to touch on the use of literacy skills in written answering of science questions…

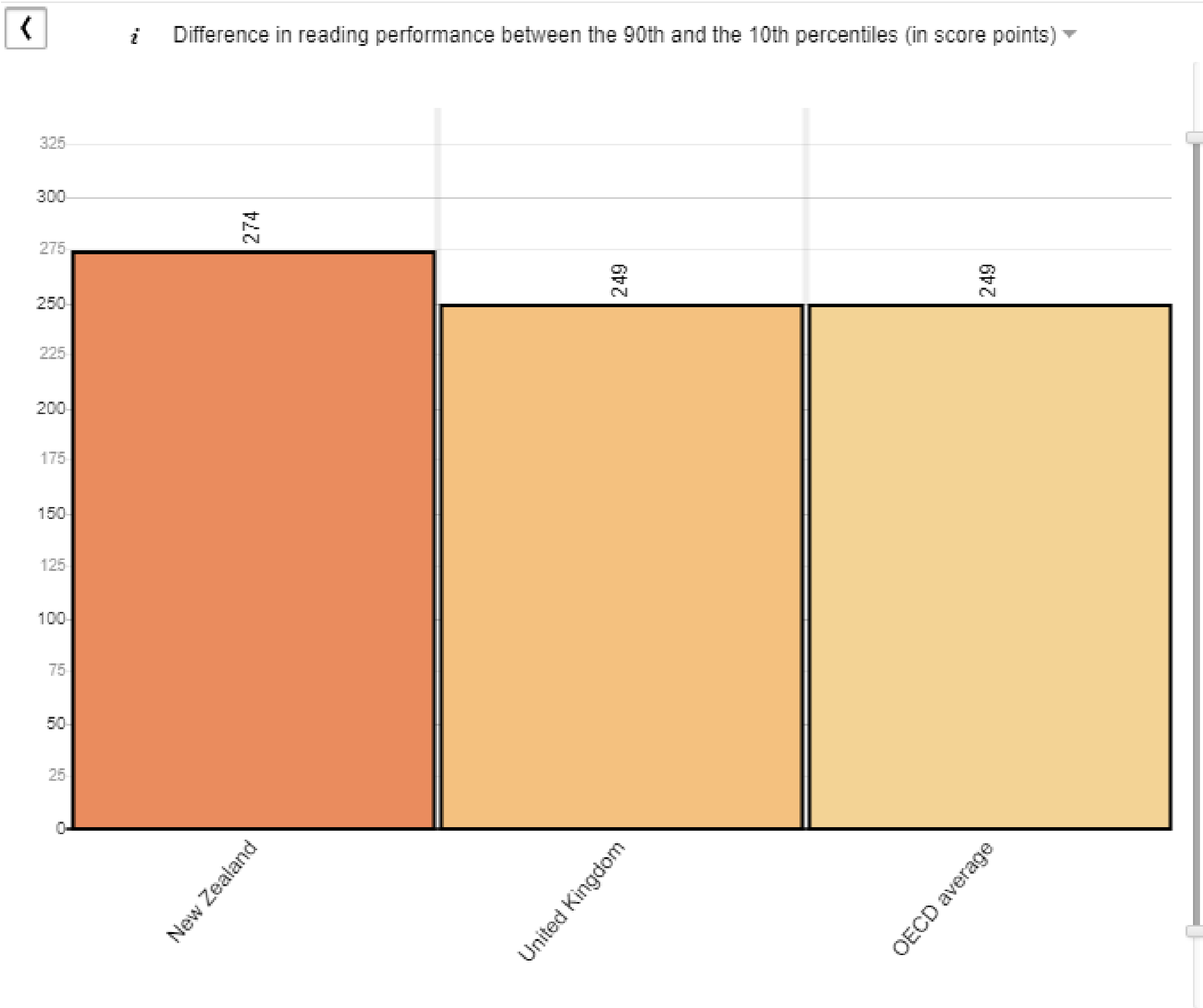
The key reflection from discussing hidden barriers generated by student (and teacher) literacy is that there is plenty of room for critical review of the printed material we put in front of teachers.

We all try to differentiate our teaching and resources to meet the science needs of our learners but do we have the options to even vary the reading age of the delivery medium?

Do we put enough emphasis on the quality and appropriateness of the text which we deliver our curriculum learning with?

There are ways that we can generate a better match between reading age and supporting learning in the sciences, but these require effort and possibly investment. We need to decide if this is an investment which will give returns, and share our ideas and experiences, across all demographics of learners.

Food for thought 1



http://gpseducation.oecd.org/CountryProfile?plotter=h5&primaryCountry=NZL&treshold=5&topic=PI

Whilst New Zealand secondary school students have **reading abilities** which are higher than average for the OECD (which makes a good headline) the **difference** in reading performance between the **highest 10% and lowest 10%** performing 15 year-old students in **New Zealand is greater than average** too.

So we have more of a range of reading abilities than expected for a well-educated country.

Is this surprising?

Does this have an impact on success in science in the secondary education sector?

Food for thought 2

Chapter 6: Forces
Effects of forces

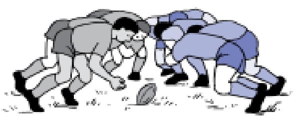
Questions from pages 93, 94 of *ESA Study Guide Year 10 Science*

Understanding

1. Complete the following paragraph.

   Forces acting in the same direction are a. ____________ to find the total force. Forces acting in b. ____________ directions are subtracted to find the total force. When the total force is c. ____________ newtons the forces are said to be balanced. When the d. ____________ acting on an object are balanced, the object is stationary or travelling at a e. ____________ speed.

2. A rugby scrum shows forces in action. In the diagram, four players from each team have formed a scrum.



   a. Each member of the team on the left exerts the same push. The total push is 6 000 N. What is the (average) push supplied by each person?

   ____

   b. The scrum is stationary because the forces are balanced. What is the total force from the team on the right? ____________

   c. If the team on the right can push with a force of 7 000 N, what will happen to the scrum?

   ____

3. The following diagram shows three horizontal forces acting on a toy car.

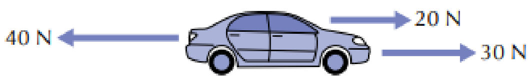
   a. What single force would have the same effect? ____________

   b. State whether this is an example of balanced forces or of unbalanced forces.

   ____

   c. Describe the overall effect of the forces on the toy car.

   ____



Thinking

In the example of the car in 3, what two forces could be pushing the car to the right?

____________ and ____________

This is an extract from a year 10 general science exercise book.

What are your first impressions of (a) the layout (b) the language?

Is the key learning being assessed obvious?

Is this dyslexic-friendly?

Would your weakest year 10 readers be able to drill down through the language without support?

What changes would you make?

Food for thought 3

This is from the 2018 NCEA Waves external…

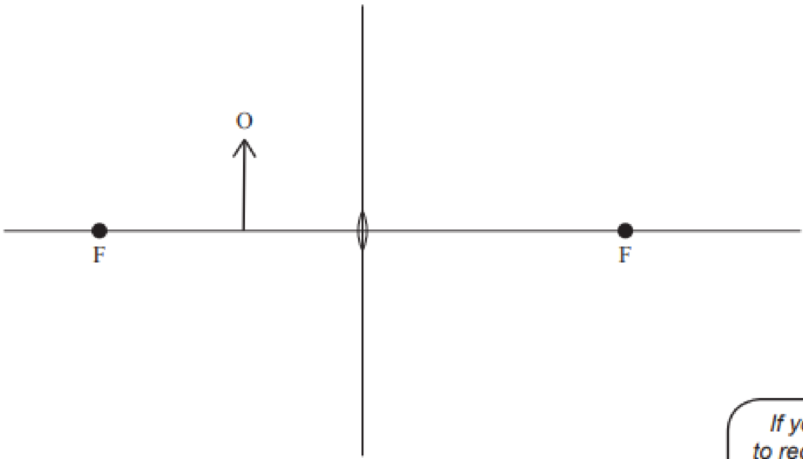
QUESTION ONE: THE ENLARGED EYE

www.123rf.com/photo_11597957_funny-boy-looking-through-magnifying-glass-with-surprise.htm

Sophie and her friend John were investigating magnifying glasses (convex lenses). Sophie laughed at the size that John's eye appeared when he placed the lens over his eye.

(a) Complete the following ray diagram to show how John's eye (the object) appears enlarged, as in the photo.

Clearly indicate its size and position.



If you need to redraw your ray diagram, use the diagram on page 9.

The lens has a focal length of 12 cm. John holds the lens 5 cm from his eye.

(b) Calculate the distance the image is from the lens, and state the nature of the image produced.

(c) If the eye (object) has a height of 2.0 cm, calculate the magnification AND the height of the image of the eye.

Are there any obvious literacy barriers to accessing the physics?

How would students with ASD interpret "the nature of the image produced"?

All questions expect two answers. Is that obvious if you're reading quickly?

What tactics could we teach level 2 and level 3 students to support the literacy decoding of worded examination questions?

On the following page there are some suggestions for short **estimation** practise exercises which could be done in an science lesson.

To scaffold the estimation process it may be helpful to indicate the units which you're expecting the answer to have when it's presented. Likewise, there may be a need to add some background information to the question to avoid students being stumped by lack of general knowledge or avoid them being distracted by having to perform research. Less able or experienced learners may benefit from a visual prompt to support the estimation process.

After completion of the exercise, which may need tight time management including prompting, it would be interesting for students to share their estimations – without judgement – and to discuss the causes of variation in their answers. If the teacher then scaffolds the process by modelling their approach to solving the problem there is then a move away from students feeling disappointed by not having the 'correct' answer because the uncertainties in estimation can then be highlighted.

We hope this helps.

Estimate the perimeter of the school playing field Units: metres	**Estimate the volume of this classroom** Units: m^3	**Estimate the total mass of students in the whole school** Units: tonnes
Estimate the mass of your house Units: tonnes	**Estimate the mass of a 1000 metre high mountain** Units: you choose	**Estimate the mass of food that you eat every year** Units: kg or tonnes!
Estimate the combined mass of the Earth's human population Units: tonnes	**Estimate the mass of air in an empty cup** Info: air has a density of around 1kg per m3.	**Estimate the volume of water in Lake Taupo** Hint: use www to find the approximate dimensions of Lake Taupo Units: m^3
Estimate the mass of a butterfly Units: kg or g?	**Estimate the length of a bus** Units: m	**Estimate the combined length of all the hairs on your head** Units: *you decide*
Estimate the distance you walk in a year. Units: *you decide*	**Estimate the distance you travel in a year.**	**Estimate the number of marbles you could fit in this classroom**

Estimate, with working, the number of chips you eat a year.	**Estimate the number of left-handed students in the school.**	**Estimate the number of mobile phones needed to balance you on a seesaw.**
Estimate how many days since you were born. Do not calculate it directly. Round the number to the nearest 100.	**Estimate your best friend's IQ**	**Estimate the number of pencils, laid end to end, that would stretch from your house to school.**
Estimate the number of carrots you could grow in a 100m x 100m field.	**Estimate the temperature of the sea on your nearest beach.**	**Estimate the number of leaves on the tree outside the principal's office.**
Estimate the number of hours per year that the teacher spends dealing with interruptions in class.	**Estimate and compare the kinetic energy of a family car travelling at 100 km/h and a cannon ball travelling at 200ms^{-1}.**	**Estimate and comment on the electrical energy consumed every day in New Zealand in charging mobile phones.**
Estimate the number of grains of sand in this bucket 	**Estimate the number of rice grains in this 1kg packet** 	**Estimate the number of stars in this image** 

And finally….

We all have our favourite typefaces for documents we produce, but how friendly are they for students with dyslexia? This year, in our ENGR141 and SARC122 introductory physics courses as Vic we've been using Arial in preference to more 'academic' and formal looking serif fonts such as Georgia or Times New Roman. Comments from students with dyslexia are very positive about this simple typeface change, and we'll be sticking with this.

Maybe this is a discussion point for your team and the inclusion staff in your setting?

Here's a link to a research project which quantified the friendliness of differing common fonts. We hope it's useful

http://dyslexiahelp.umich.edu/sites/default/files/good_fonts_for_dyslexia_study.pdf

Good Fonts for Dyslexia

Luz Rello
NLP & Web Research Groups
Universitat Pompeu Fabra
Barcelona, Spain
luzrello@acm.org

Ricardo Baeza-Yates
Yahoo! Labs &
Web Research Group, UPF
Barcelona, Spain
rbaeza@acm.org

ABSTRACT

Around 10% of the people have dyslexia, a neurological disability that impairs a person's ability to read and write. There is evidence that the presentation of the text has a significant effect on a text's accessibility for people with dyslexia. However, to the best of our knowledge, there are no experiments that objectively measure the impact of the font type on reading performance. In this paper, we present the first experiment that uses eye-tracking to measure the effect of font type on reading speed. Using a within-subject design, 48 subjects with dyslexia read 12 texts with 12 different fonts. *Sans serif*, *monospaced* and *roman* font styles significantly improved the reading performance over *serif*, *proportional* and *italic* fonts. On the basis of our results, we present a set of more accessible fonts for people with dyslexia.

The main contributions of this study are:

- Font types have a significant impact on readability of people with dyslexia.
- Good fonts for people with dyslexia are *Helvetica*, *Courier*, *Arial*, *Verdana* and *Computer Modern Unicode*, taking into consideration reading performance and subjective preferences. On the contrary, *Arial It.* should be avoided since it decreases readability.
- *Sans serif*, *roman* and *monospaced* font types increased the reading performance of our participants, while *italic* fonts did the opposite.