Missing the answer

Sophie Mead’s essay ‘Solar power: is it worth the energy?’ (Phys. Educ. 45 17) missed out a little publicized energy source. No mention was made of ground- or air-sourced heat pumps, which can give a 3 kW output for every kilowatt of power input. They also work in both summer and winter. I feel that if these physics/engineering solutions are not discussed then the public will just ignore all green energy upgrades as too costly or too long a payback time. Perhaps a future issue could look at these devices because they are now a mature technology.

Richard Walder

Down to interpretation

Since starting teaching and experiencing the ‘marking side’ of multiple-choice papers I have been curious about the varied methods by which results are interpreted. For instance, it is often practice to deduct a mark for every wrong answer and I even heard once (in a university faculty) that every paper was deducted a fixed percentage from the grade according to the number of choices there were in each question: that is, for example, to remove a fixed 20% from a multiple-choice paper that had five choices for each question.

After marking a class set of multiple-choice papers I wondered if it were possible to find a way to adjust my marks to indicate how much of the subject my pupils actually knew; that is, to adjust the mark for those pupils who guessed some answers but not punish those pupils who knew it all.

What follows was intended as a way, should we look for an alternative to simply adding up the marks and setting grade boundaries, to adjust multiple-choice scores so that the examiner/teacher has a more realistic feel for the number of questions their pupils can actually answer. What it is in fact is more of a simple, playful, piece of maths that made a welcome distraction one night from marking (if only I’d set the test online!) and later revealed a very obvious conclusion.

Let us say that a pupil sits a multiple-choice paper. The paper has $M$ questions, each having $n$ possible answers. In this paper the pupil attains a score of $m$, a score that we would assume to be greater than the number of answers that the pupil legitimately knew (that is, we assume that the pupil guessed at some). A more realistic score—one more desirable to the examiner for feedback—would be $m’$ where:

$$m’ = m - g,$$

where $g$ is the number of guessed answers.

$g$ is calculable from the number of questions, $z$, that the pupil did not know the answers to, such that:

$$g = \text{probability of guessing} \times z = \frac{1}{n} \times z = \frac{z}{n}.$$  

$z$ is not a number immediately accessible to the examiner but is related to the realistic score $m’$ and the total marks, $M$, simply by:

$$z = M - m’.$$  

Substitution gives us:

$$m’ = m - \left(\frac{M-m’}{n}\right)$$

and rearrangement gives us:

$$m’ = \left(\frac{m-M}{n} \right) \left(1 - \frac{1}{n}\right).$$

$m$, $M$ and $n$ are immediately available to the examiner and can be used to find the more desirable value $m’$, the number of answers that the pupil probably knew.

The equation is therefore such that if a pupil was to answer completely correctly ($m=M$) then $m’=M$ and the pupil would maintain their immaculate score. If, however, a trained chimp attempts the paper and scores —then $m’=0$ and the chimp’s lack of knowledge is revealed.

Being a relatively new teacher at the time and proud of my little equation, I e-mailed my ‘grand solution to all multiple-choice marking’ to my colleagues. ‘Hmm’ was the gist of the responses, or ‘well done, but I think we get what we need just by setting grade boundaries’. They were probably right. It suffices to say that neither I nor anybody else has yet to use my equation. But just wait until I hit them with else has yet to use my equation.

Embarrassingly I realized much later that the mechanism of the equation is curiously identical to subtracting the fixed percentage from every score, followed by scaling all the marks to make the maximum 100%. Fig-
L E T T E R S

Figure 1 shows this for an example of a ‘five-choice’ multiple-choice paper and reveals the simplicity of the equation. It is sweet that my derivation, based on a sound statistical argument, brings out the same conclusion as a crude linear ‘chop and scale’ method (though maybe in hindsight this was predictable). I am sure that this won’t be the last time I go around the houses to arrive at a painfully obvious conclusion.

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The dangers of separation

Very soon secondary schools in England and Wales will be receiving draft specifications that lay out the science GCSEs (for 14–16 year olds) for teaching from 2011. These are based on statutory criteria recently revised by the government’s Qualifications and Curriculum Development Agency. Crucially, the criteria have not changed in any major way and so the specifications are not expected to either. In particular, we will still have the qualification model born of the 2006 reforms of the science curriculum.

GCSE core science: compulsory for all, usually taught in year 10, in 10% curriculum time, delivering scientific literacy but not very much science.

GCSE additional science: technically optional, but in reality studied by the majority, usually taught in year 11, also in 10% curriculum time, now delivering in one GCSE the actual science that used to be in two.

Separate GCSEs in biology, chemistry and physics: formed of some further units of study to raise the core and additional units up to an optimistic level; there is often no extra curriculum time allocated to delivering these.

Given that this young (4 year old) model will continue to exist for some time to come, it is unfortunate that I feel quite strongly that it is riddled with deep flaws—flaws that are subtle and complex and could not have been anticipated in advance. They are missed by current evidence. For instance, yes, AS physics numbers are up but how many students drop out in their first year or don’t go on to A2 because they couldn’t cope or found that it was not what they were expecting? Nor are they picked up by low-key questionnaires that the QCDA sends out in lieu of actual consultation and in which the important questions are never asked. Until the ephemeral evidence of those delivering these courses is widely sought, progress will not occur.

The 2006 reforms probably do provide a better opportunity for a scientifically literate citizenship of the future, as they were intended to, but at what cost? I would argue that the same reforms have also reduced our ability to provide society with properly trained scientists, doctors and engineers. In 20 years’ time, average scientific literacy will be up, but only by dragging the ends of the spectrum towards the middle.

By making core science compulsory for all, the teaching of all science is effectively reduced to 10% of curriculum time. The other 10% of allocated time used for core science is now more socioeconomic common-sense analysis and debate than ‘science’, e.g. ‘what factors influence where wind farms should be sited?’ rather than ‘how does the electric generator inside a wind turbine produce the electricity?’

Children are not all the same and one science education for all is not appropriate. By forcing all pupils to study core science we leave less curriculum time for actual science (‘additional’ is a misnomer), and despite what various people would have us believe, this is not adequate preparation for A-level (or rather, it wasn’t—removal of content from the A-level has attempted to fix that worrisome detail).

More subtly, the division of the curriculum into ‘core’ and ‘additional’, plus extra units for separate sciences, has repeatedly cleaved coherent concepts into pieces. Many ideas are now taught (or half-taught) in the wrong order. For instance, ‘core’ expects step-up and step-down transformers to be explained, but the study of current and voltage is a year away in ‘additional’ and electromagnetism is only taught in the extra physics units.

‘Core’ and ‘additional’ can be taught in parallel, but in reality very few schools do this. To do so
would almost certainly place their students at a disadvantage when compared to the students of ‘teach to the test’ schools. Besides, is it only me who finds it just a little bit patronizing to be told ‘you can reorder our shambles if you want to’? Why should I? Why can’t it just be right in the first place?

Imagine this alternative instead: students study GCSE science or GCSE biology, chemistry and physics. The former prepares students to take their place as responsible and able citizens of a technological democracy. The latter, properly thought out over a coherent five years (instead of two isolated years that follow three previous isolated years) of secondary school so that it can still be finished in a 20% time allocation, prepares students to go on to further study.

Crucially, the three separate sciences would have their own subject criteria that exist quite independently of the criteria for ‘science’ and which have received substantial input from end-user stakeholders such as industry and universities. What is more, all four courses are structured by practising teachers who know better than anyone else the most successful pedagogical approaches.

To think that this points to a return to O-levels/CSEs is to exhibit oneself as a reactionary looking to score quick politically motivated points. There are viable, straightforward options, if one is willing to take the time to consider them.

For too long the science curriculum in England and Wales has been structured to accommodate uniformity. It is time to accept that, beyond a certain point, this is wrong—and to be secure enough to recognize that such a standpoint is not elitist. In fact, it is the opposite, because it recognizes and supports the very different needs of very different learners. Making our children all wear the same gloves is an insult to too many of them and by doing so we should feel ashamed. The current system is not alternative gloves, it is just a matter of how much you push your hand into the same glove.

The people responsible for the current state of affairs like to defend it, but in doing so they become reticent to recognize, let alone address, its problems. And those in politics who would like to be responsible, by comparison, want to assert their rival authority by stating that they would immediately sweep away all that has come before and start over. That, too, is simplistic and shortsighted. The curriculum is 90% there. We don’t need our heads in the sand and we don’t need a clean slate. We need the courage to finish what we started.

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Filling in the blanks

I have two comments on the interesting Frontline paper ‘Emperor’s crown model teaches fluidics’ (Phys. Educ. 45 137).

First, the authors state without explanation in the second to last paragraph that when the crown is in the water the water level increase is less than the previous water level decrease when the crown is falling in air. For completeness, here is the explanation.

When the crown is falling in air, the water level decrease is:

$$\frac{\rho_c V_c}{\rho_w A}$$  \hspace{1cm} (1)

where \(\rho_c\) is the density of the crown, \(V_c\) is the volume of the crown, \(\rho_w\) is the density of water and \(A\) is the surface area of the pool.

When the crown is in the water, the water level increase is:

$$\frac{V_c}{A}.$$  \hspace{1cm} (2)

This water level increase is less than the previous water level decrease because \(\rho_c > \rho_w\). Therefore, there is a net water level decrease, resulting from the crown falling off the emperor’s head and sinking to the bottom of the pool, to level L2, given by:

$$\left(\frac{\rho_c}{\rho_w} - 1\right) \frac{V_c}{A}.$$  \hspace{1cm} (3)

Second, the authors did not mention the relationship between the final water level L3 (when the emperor is underwater to retrieve the crown) and the initial water level L1 (when the emperor is floating with the crown on his head). When the emperor goes underwater, the water level increases from level L2 to level L3 by

$$\left(1 - \frac{\rho_c}{\rho_w}\right) \frac{V_e}{A}.$$  \hspace{1cm} (4)

where \(\rho_c\) is the emperor’s density and \(V_e\) is the emperor’s volume. The relationship between water levels L1 and L3 is determined by the water level increase in equation (4) and the net water level decrease in equation (3).

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