Physics Students Learn Nothing, So Try History of Science

SANJOY MAHAJAN

Cavendish Laboratory, Astrophysics, Cambridge CB3 0HE, UK. Email: sanjoy@mrao.cam.ac.uk

ABSTRACT. Standard methods of teaching physics are useless. I want to give you evidence or, if you like, ammunition. When people say that there is no time to incorporate history of science into the curriculum, you can point out that standard methods do not teach physics, so radicalism cannot hurt. Students might even find physics fascinating. My examples come from interviewing students in the Cambridge University physics course. Even though they are among the most talented in the United Kingdom, they have great difficulty with fundamental mathematical and physical concepts. They can solve exam problems yet cannot reason qualitatively – they cannot think like physicists.

If you propose to improve science teaching by incorporating history of science, you will be told that history is beautiful but sadly time and life are short. I want to provide you with a counterargument: In the usual teaching, students learn almost no physics or mathematics, so the lack of time is irrelevant. That point does not show that we should incorporate history and philosophy of science into the curriculum; I leave that (large) part of the argument to Michael Matthews.[1] The following examples come from interviewing Cambridge University physics students, among the most talented in the United Kingdom. Their misconceptions reveal problems with our teaching methods.

Mathematical Difficulties

My 10 first-year students were studying Stirling's approximation to $\ln n!$ when n is large (Arfken 1985, pp. 555–558). As part of the problem, they correctly drew Figure 1. They were then asked to decide whether the integral approximation,

$$\int_1^n \ln k \, dk,$$

overestimates or underestimates $\ln n!$. Students ignored their own graph. Instead they did the tricky integral

$$\int_1^7 \ln k \, dk = 7 \times (\ln 7 - 1) + 1 = 7.62...$$

and used to a calculator to find

$$\sum_1^7 \ln k = 8.52... \, .$$

They then noticed that 8.52 was more than 7.62; therefore the 'integral approximation must be an underestimate.' None concluded the same by noticing that the rectangles protrude beyond the smooth curve.

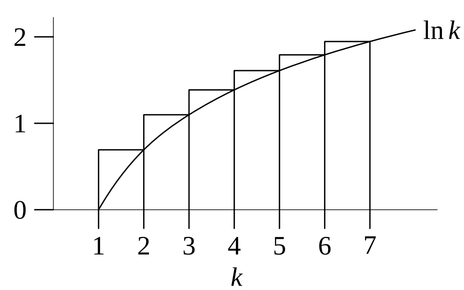


Figure 1. *Deriving Stirling's formula. The area under the smooth curve approximates the exact result, which is the area under the rectangles.*

This correct but brute-force solution reminds me of Wertheimer's (1959, pp. 130–131) question:

$$\frac{274 + 274 + 274 + 274 + 274}{5} = ?$$

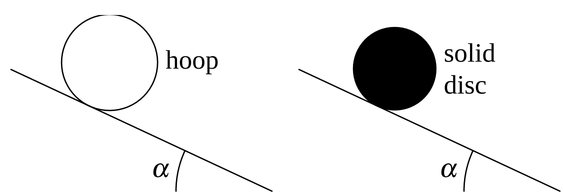
Students who got the joke laughed. Others, showing that they did not understand the meaning of multiplication, 'started at once with tedious figuring or begged to be excused from such a cumbersome task.'

No Qualitative Understanding

To find out the prevalence of rote learning, David MacKay and I used dark Swiss chocolate to entice 62 students away from their busy schedules and into a survey (7, 21, 26, and 8 students in years 1–4, respectively). We asked nine qualitative-reasoning questions, varying in difficulty from Newton's first law to the bending of beams.[2] The simplest question required only the first law:

> Two people are on opposite sides of a rotating merry-go-round. One throws a ball to the other. In which frame of reference is the path of the ball straight when viewed from above?
>
> A. merry-go-round only
> B. earth only
> C. both earth and merry-go-round
> D. neither

The results were not encouraging: 58 percent correctly chose B but only 40 percent were sure. (To account for guessing, we asked students always to make a second choice, which could be another answer, 'I am sure of my first choice', or 'I have no clue'.) If we had said 'Use the first law', almost every answer would have been right; the law, in short, is not part of students' intuitive reasoning even after many years of studying physics.[3]



Compare the accelerations:

A. hoop is faster
B. disc is faster
C. same
D. depends which is heavier
E. depends on diameters
F. depends on slope α

Figure 2. *Rolling problem. Calculation is not needed, only a qualitative understanding of rotational energy along with the idea that the hoop's mass lies towards the edge more than the disc's does.*

A second problem (Figure 2) required qualitative understanding of rolling. Here 35 percent correctly chose B but only 14 percent were sure. In tutorials on this problem, first-year students told me that 'Since heavier objects fall faster, heavier objects should roll faster'! However, when asked directly 'Do heavier objects falls faster?', like most students they know to say 'same speed' and cite Galileo as proof, even when they do not believe it. This pattern illustrates the American theory of the British accent: that it is a fake attained through lengthy practice. So if you surprise a Brit in the middle of the night, he will curse you in American vowels. I have not yet tried the accent test, but the theory describes how students do

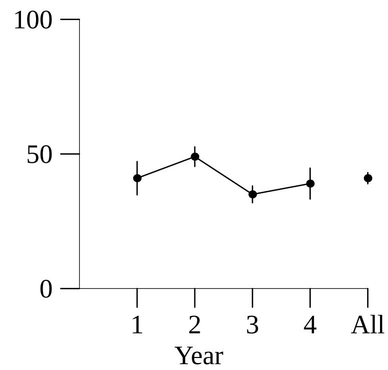


Figure 3. *Percent correct for all nine questions combined. The 'All' data point is from pooling all surveyed students.*

physics: In an unfamiliar context – rolling motion – the memorised response is not available, so the answers show how a student really thinks.

In the overall results (Figure 3), the bump for the second-year students does not herald glad tidings. These students had discussed every problem in their Dynamics lecture course a few months before the survey, using the peer-instruction method of Eric Mazur (1997). One purpose of the survey was to test the value of such discussions. After the survey, many students commented that they 'remembered the questions but not the answers.' So even peer-instruction discussions hardly helped.

Qualitative understanding is unrelated to standard measures of ability. The correlations between the survey score and the scores on the University's official exams are: 0.28, 0.28, and -0.04 for students in years 2, 3, and 4 respectively (the first-year students had not yet taken their exams).

Our Chance

Standard teaching leaves most students unable to use, let alone understand basic ideas of physics. Many, however, develop great skill at examination problems. So let's try a different way of teaching. Pick a few topics (Morrison 1964). I'd be happy if, after one year of studying physics, students understood just Newton's first and second laws.[4] Then choose historical examples and debates involving these ideas, and spend the whole year on them, introducing methods of estimation and other physics ways of thinking. Michael Matthews' *Time for Science Education* (2000) is a rich source for such material. This course would be as much fun to develop as to teach.

ENDNOTES

1. See Matthews (1991, 1994, 2000). Mahajan (in press) suggests a few physics problems based on the historical episodes in Matthews (2000).

2. The full results are available at `http://wol.ra.phy.cam.ac.uk/teaching/survey`.

3. The students had great trouble even when discussing the problem at length during lecture, so I suspect that the difficulty is a misconception about circular motion, not an uncertainty about whether the earth is an inertial frame.

4. Ernst Mach observed: 'I know nothing more terrible than the poor creatures who have learned too much...What they have acquired is a spider's web of thoughts too weak to furnish sure supports, but complicated enough to produce confusion' (1894/1943, p. 367).

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