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Assessment

Making Maths Problems More Natural

Maths problems on a worksheet (or an exam paper) often fail to engage students with their own logic. Rob Eastaway suggests a way to fix them.

In 2015, a GCSE maths exam question hit the headlines. Newspapers carried it on their front pages, the BBC's Today programme gave it a five-minute slot and Sky News even had a live guest on their prime-time broadcast to talk them through the solution.

What is remarkable is that the problem was a fairly routine one, featuring somebody called Hannah taking sweets from a bag.

You probably remember the story. You might even have been in the cohort that sat the paper.

I want to set you a challenge. I will remind you of the opening lines to the problem, and then I want you to guess (or try to remember) exactly what came next.

Here's the set-up for the question:

> There are n sweets in a bag.
>
> 6 of the sweets are orange.
>
> The rest of the sweets are yellow.
>
> Hannah takes a random sweet from the bag. She eats the sweet.
>
> Hannah then takes at random another sweet from the bag. She eats the sweet.

That's all quite clear. Now what line would you expect to come next?

The majority of people who read this for the first time expect they're about to be asked about the chance that Hannah got (say) two orange sweets. That isn't what happens. Instead, the candidate is told:

> The probability that Hannah eats two orange sweets is 1/3.

This was followed by the question that sent social media into meltdown:

> Show that $n^2 – n – 90 = 0$.

The situation begins naturally enough. Hannah takes sweets from a bag and eats them. But then the story takes an unnatural turn. In real life we encounter surprising outcomes and ask ourselves 'what are the chances?' Here, the probability has been handed to us and we are asked to work backwards.

Just think of random encounters you have experienced in life. You were on holiday and bumped into a friend who lives down the road from you; you received three emails and each of them was from a different person called Kate. The natural question that jumps into your head is 'what are the chances?'

Natural and Unnatural Problems

Hannah's Sweets is an example of what I call an 'unnatural' maths problem. It's a situation that has been contrived in order to test mathematical reasoning, but which is unlike any problems that most people will encounter in the real world.

An unnatural problem is not the same as an implausible one. Plenty of maths word problems are unrealistic. For example, GCSE exams often feature shops that sell packs of six green pens (when did you last see one of those?), but however contrived, the situation that the student is trying to solve is at least clear.

Contrast that, however, with a GCSE problem that began:

Alice is 7 years older than Kay. Minnie is twice as old as Alice. The sum of their three ages is 77.

So far so good… and then the question arrives:

> Find the ratio of Kay's age to Alice's age to Minnie's age.

The issue isn't that the calculation is difficult. It's this: why would anybody want to know the ratio of the three ages?

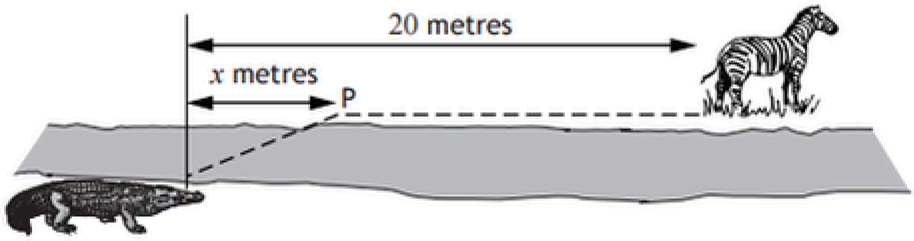
The Crocodile Problem

Let's return to 2015, when by coincidence, another maths exam question hit the news headlines. The Scottish Qualifications Authority (SQA) set a question about a crocodile figuring out the best strategy for catching a zebra on the other side of the river, reproduced below.

8. A crocodile is stalking prey located 20 metres further upstream on the opposite bank of a river.

Crocodiles travel at different speeds on land and in water.

The time taken for the crocodile to reach its prey can be minimised if it swims to a particular point, P, x metres upstream on the other side of the river as shown in the diagram.



The time taken, T, measured in tenths of a second, is given by

$$T(x) = 5\sqrt{36 + x^2} + 4(20 - x)$$

(a) (i) Calculate the time taken if the crocodile does not travel on land. **1**

(ii) Calculate the time taken if the crocodile swims the shortest distance possible. **1**

(b) Between these two extremes there is one value of x which minimises the time taken. Find this value of x and hence calculate the minimum possible time. **8**

Like Hannah's Sweets, this problem hit the news headlines with students protesting about how hard it was. But let's set aside the difficulty. For me, a key problem was that it was an unnatural context.

The natural problem would be for the crocodile to use its reptilian brain to consider what the best tactics are for catching the zebra. Yet here we've been presented with a formula that has just appeared from somewhere. On top of that, any student who's watched David Attenborough programmes will know that a crocodile probably wouldn't choose this strategy at all.

But perhaps the biggest issue is that the interesting work of deciding how to represent the situation mathematically has already been done by somebody else.

Modelling Versus Computation

This distinction between natural and unnatural problems has been explored by the American mathematics educator Dan Meyer.

He argues that many textbook and examination questions begin halfway through the story. The student is presented not only with a situation, but with all the relevant information and, crucially, with the question that somebody else has decided is worth asking.

The student is never given the chance to feel what Meyer calls 'the itch' – that moment of curiosity when you genuinely want to know the answer. Nor are they usually asked to make the decisions that lie at the heart of mathematical modelling: What information matters? What assumptions are reasonable? Which mathematical tools might help?

One of Meyer's most famous examples shows a short video clip of him throwing a basketball towards a hoop. The video freezes with the ball about halfway towards the basket.

The question that arises naturally is: Will the ball go in? To find out, you need to plot the path that the ball has taken so far and build the parabola that will show its entire flight.

Compare that with what you might find in an exam question:

> 'A basketball is projected at an angle of 52° with an initial speed of 8.2 m/s…'

Why are exam questions like this? It's partly because it's much easier to assess answers to computational questions than students' diverse attempts to model a situation. There's little place for 'curiosity' in an exam room, since every individual has different interests and motivations.

The downside is that if students only ever experience mathematics through exam-style questions, they can end up with a distorted picture of what mathematical thinking actually is. They become very good at answering questions that somebody else has decided are worth asking. What they see less often is the process by which those questions arise in the first place.

Creating Natural Problems

What this means is that if we want students to experience natural problems, this needs to happen through tasks that sit outside traditional exam questions. Unfortunately, every teacher knows that with such a packed curriculum, there's very little space to enrich the problem-solving experience. Furthermore, turning unnatural problems into natural ones is quite a skill. But that doesn't mean we shouldn't try.

Let me tell you about a fairground game called 'Treble Your Money'. The idea of the game is to take two balls out of a bag, which contains six red balls and some black balls. It costs £1 to play, and if both of the balls that you take out are red, you win £3.

Would you play this game?

What's that, you want more information first? You want to know how many black balls there are?

I won't reveal that, but instead I'll ask a question. Would you play if I told you there are six reds and two black balls? I think you would, because the chance of getting two reds would surely be very high. On the other hand, if there were six reds and 100 black balls in the bag, I suspect you would feel the game was a rip-off.

There must be some tipping point, a number of black balls in the bag where you would flip from wanting to play to not wanting to play – a 'fair' number. What do you reckon that tipping point is? Six black balls? More? Fewer?

This is a problem that you care about because you have some skin in the game. And guess what: the maths underlying this is exactly the same as in the

Hannah's Sweets problem at the beginning, only this time the problem has emerged naturally.

The maths hasn't changed; what has changed is the student's relationship with the problem. Instead of answering a question that someone else has chosen, they are trying to resolve something that they genuinely care about. That changes everything.

Rob Eastaway is an author and speaker, and the Director of Maths Inspiration, a national programme of theatre-based lecture shows for 16-17-year-olds. His books include *Maths On The Back Of An Envelope* and *Much Ado About Numbers* (about maths and Shakespeare). He's a frequent guest on BBC Radio 4's award-winning podcast *More Or Less.*
