Developing Numeracy Skills Across the Curriculum

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Business leaders regularly complain that school leavers have levels of arithmetic so poor that they cannot accomplish basic tasks at work. In a recent article for Channel 4 news (see: http://bit.ly/H03UjL), the head of education and skills for the CBI is quoted as saying that employees should be able to; '… work out what a 30% discount is without doing it on the till'. OK, I would challenge you now, in your head to work out a 30% discount on an item priced at £23.79, without using the till. Remember when Chris Woodhead, former head of Ofsted was asked how much a half of three-quarters was (see: http://bbc.in/H048rj). This came hard on the heels of two government ministers getting the simplest of times tables questions wrong, so he simply refused to answer.

Importance of context

There is plenty of evidence to demonstrate that the way we use arithmetic to solve a problem in a practical context is heavily dependent on the context itself. So, simply dressing arithmetic problems up in a practical context, in a school setting is not supportive of learning how to solve problems in the real setting. Some excellent research from Brazil was carried out looking at street children selling bubblegum. This is reported in the book, Street mathematics and school mathematics (Nunes et al, 1993). What the researchers found was that children were able to solve very complicated arithmetic problems on the street, involving divisions by 144 (since the gum is sold wholesale in boxes of a gross) to find retail prices and profit. However, when presented with seemingly identical problems framed in the same context and with the same calculations, in a school setting, their facility plummeted (Nunes et al, 1993). So, it seems that the school does worse than fail to develop this skill, it actually fails to recognise it when it is in fact present already. In part, this is down to the expectation on the part of the solver, that the school will only recognise an accepted method, so even when we have successful methods of our own, we are fearful that they are not the correct method. As manager of Number Partners (see: www.numberpartners.org), a volunteering scheme that gets business people to play maths games with pupils in schools, I trained many cohorts of volunteers. Frequently, I would be in a major city bank working with managers and senior executives, who were extremely highly qualified and evidently highly numerate. I would ask them to combine numbers in their heads, for example 147+149. When asked to reflect on how they did it, we would always get a range of different methods. I will explore these later on, but suffice it to say here, only very rarely did they use the way they were taught to do it at school.

Overcoming fear of failure

Additionally, the overwhelming characterisation of maths as being the subject where there is only one right answer, brings with it a debilitating fear of failure. No less a commentator than Malcolm X, more well known for his thoughts in a political arena than on school maths, said:

I'm sorry to say that the subject I most disliked was mathematics. I have thought about it. I think the reason was that mathematics leaves no room for argument. If you made a mistake, that was all there was to it. (X et al, 1992)

It is important to recognise that professional mathematicians do not see maths this way, and those of us who love the subject are delighted by the search for patterns and relationships and the utter joy when everything fits into place. To get a glimpse of this, I strongly recommend watching the opening sequence to Simon Singh's documentary on the proving of Fermat's Last Theorem, in which Andrew Wile's, the Cambridge mathematician who solved this 200-year-old problem, one of the most famous in mathematics, reflects on the moment he realised he had done it (see: http://bit.ly/H05BO9). He simply stares at the camera and, in remembering, he is so overcome, he cannot continue.

On the other hand, the fear of classroom failure is food for satirists everywhere. It is an easy matter to find cartoons that remind the reader of the terror they faced at school. Charles Schultz, the Peanuts cartoonist provides a rich collection of 'math anxiety' strategies, notably Linus, who avoids engaging with maths using a range of avoidance mechanisms; 'Sixteen times twelve?', 'I know!! Benjamin Franklin!', 'Really? Sorry Ma'am', 'Just a wild guess' (see: http://bit.ly/H06J4s). It is astonishing how frequently in my Numbers Partners sessions, an informal discussion would kick off with stories of times in school maths lessons when the participants could still remember the horror of failure and the sense of humiliation. One presumes that, given sufficient time and motivation, Chris Woodhead would have been able to solve the problem, but not with a reporter, ready to delight in his discomfort, on camera, standing over him.

While this presents a pretty bleak picture, maths departments and school managers will not be successful in engaging teachers of other subjects in developing numeracy across the curriculum unless we acknowledge the elephant in the room: that people have trouble with maths and, as I have claimed, maths education is in part, to blame.

Moving forwards: three issues to address

So, how can we move forwards? It seems to me that there are three essential areas that we need to attend to.

1. There should be a consistent approach to how teachers react in supporting learners solve arithmetic problems.
2. There should be consistency in the way that mathematical ideas are referred to and used, notably algebra and graphing and the use of statistics.
3. Problem solving should be developed so that there is a genuine collaboration across departments. Mathematicians are responsible for the mathematics in the problem solving process, for example, setting up and solving the equations. Scientists are responsible for the science, for example designing and enacting the experiments. Geographers are responsible for setting the parameters for the problem, for example in describing and analysing weather patterns. However, all of these departments would work together with the goal of engaging with the problem.

1. Consistent Numeracy

Good numeracy is a matter of practice. Intriguingly, whereas many of my Number Partners volunteers went to school long before the numeracy strategy, almost all of them, when asked to solve an arithmetic problem in their heads, use the ideas that pupils are trained to use, in contemporary primary schools. It would be a good test now to do this experiment: look at the problems below(and I know you will start breathing faster just at the thought of it) and solve them in your head. You are only allowed to write down the answer, no working out. Then, straight after doing this, jot down, in any form you like, how you did it. No cheating, don't read on until you have done this!

Sample maths problems
Solve these in your head:

- 147 + 149
- 224 ÷ 4
- 162 – 28
- 8 × 7

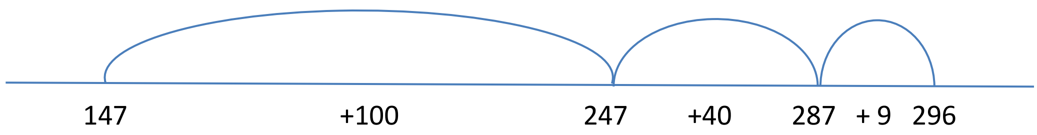
OK, now that you have your answers and your notes, we can continue.

The most important thing to say, is that if your method works for you, stick with it. The mathematics department may want to develop efficiency and primary schools certainly do this, but outside of maths, it is vital that people find a method that works, so they become sufficiently confident that when they see numbers to combine, they will get on and give it a go.

With 147 + 149 it is common to see that these are both very close to 150, so we can do 150 + 150 = 300. Now that we are close to the answer, we can take off 3 (for the 147) and another 1 (for the 149) and that make 296. Equally, a lot of people see that we have two 140s makes 280 then add on the 7 then the 9 to make 296. Some people break it up further, with 100 + 100, then 40 + 40 then 7 + 9 then put the parts together. Others, will add as they go; 147 + 100 = 247, then 247 + 40 = 287 then 287 + 9 = 296.

A key point is that in the past, we would decide on a method when we saw the operation ("ah, it's an addition so I'll do it this way …") whereas in practice, people look at the numbers and decide on a method ("they're both close to 150, so I'll do this …"). From the point of view of the teacher supporting the learner, firstly, if problems like this crop up, they must encouraged to give it a go. Secondly, the teacher must avoid trying to explain how to do it. Clearly, if a group of bankers with maths degrees attempt these problems differently to each other, then someone else's method is no help. Instead, they must keep the process going; just give a helpful prompt to encourage them not to give up. There are a number of good prompts that we'll consider, but the basic principle is the most important point: keep the process going.

Notice that the first strategy is very neat, and is practiced in primary schools as the nearest tens strategy. If you can find nearby numbers which are easier to work with, then you get close to the answer (which makes you feel much more comfortable) then you can allow for the differences. Sometimes a near ten is just as good, so deciding to go up to 150 or down to 140 is a personal thing. Breaking the problem into parts and dealing with the parts separately, is called partitioning and works well for some people. Adding as you go is interesting because this is how pupils can use a number line. This is just a line that we can use to track though a calculation. In primary schools pupils spend a lot of time practicing with a number line. In secondary schools it is enough to suggest drawing a line and see if it helps:



There are many different ways to use a number line to help with this problem, so it is important to avoiding guiding.

In primary schools, pupils practice doubling and halving, so suggesting this is helpful. 224 ÷ 4 is just 224 halved and halved again, that's 112 then 56 … easy! 162 – 28 can be very nicely done using an 'equivalence'. You know the difference stays the same if you add two to both numbers, so the answer is the same as 164 – 30 which is 134 … easy again! Actually, a number line is good for this one too, you need to know how much to add to 28 to reach 162, so we just count up on our number line.

Finally, everyone agrees that it is good to memorise your times tables, so primary schools continue to work at this. However, it was 8 × 7 that the government minister famously said was 54, so we mustn't be too puritanical about this. Instead, I find that my highly qualified volunteers rarely 'just remember'. Most of them remember 7 × 7 is 49 and add another 7, or that 5 eights are 40 and add two more eights, and so on. So, strangely, it is not a case of 'just remembering', instead all we have to say is, "well, what do you know that might help"?

Calculator use
It is very important to have a whole school policy on calculator use. As a rule, I would suggest that students should be expected to work out number problems in their heads, if the numbers are small enough and the answers are exact. The examples I have given should all be possible. If tricky numbers are going to crop up, or answers will be expected as decimals, then not only should calculators be allowed but they should be expected. It is no use having a lesson destabilised because some students can do the calculation quickly and accurately and others cannot. Strangely, I have been in many secondary schools where the maths department doesn't have a policy on calculator use and this suggests that they haven't formed a view of how students should handle numbers. This is an essential element in any policy.

So, having decided that this is a number problem for which the brain alone is the correct tool, teachers in all departments should encourage the student to find a solution and to keep them going with a prompt to try something new, but not with a method.

Examples of prompts to encourage students to try something new

- "Can you see numbers close to these that would be easier to deal with?"
- "Would it be easier the other way round?"
- "Could you break it up and work on the bits separately?"
- "Could you use doubles or halves?"
- "Can you see an easier problem with the same answer as this one?"

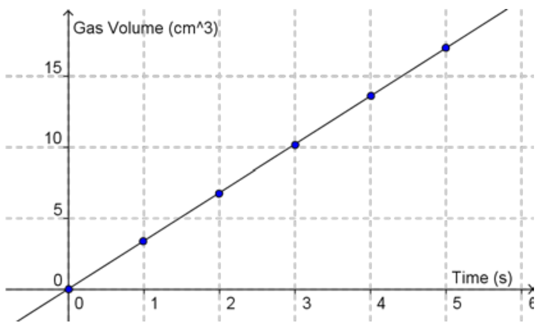
- “Would it help to jot down a number half way?”
- “Would it help to use a number line?”

Practice makes perfect

The maths department needs to be regularly practising these mental numeracy methods with their students. They will quickly forget if this does not happen. Also, for those who worry that students who use a calculator will never learn the dark arts of long multiplication and division, then fear not. The maths department will be systematically training them in these arcane practices, because all hues of government are convinced of their worth and they will remain central to any education. However, even here there is opportunity; strangely, long division becomes a very powerful technique in A-level modules (when dividing one piece of algebra by another), and working out how different methods of long mulitiplication work is an intriguing exercise. The well-known column method familiar in the UK, is only one of many methods. The so-called Russian method (see: http://bit.ly/H0gLCA), well known in Russia, relies on excellent knowledge of doubles and halves and and the Vedic (Indian) method called gelosia (see: http://bit.ly/H0h4gB) is often a massively liberating moment for students who see that they can do long multiplication by hand. Students can be supported to consistently use written methods, if that is considered important, but a range of methods, or perhaps focusing just on gelosia, may be the best policy.

2. Consistent Mathematics

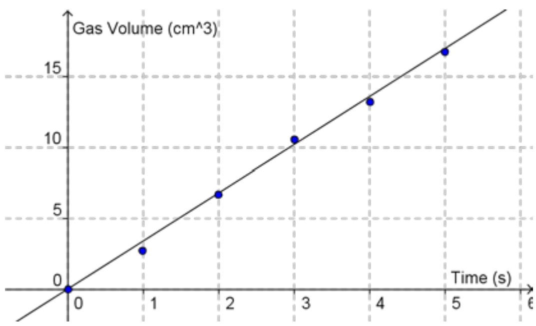
The biggest battle in the war over good maths is always fought between the maths and the science department. The battleground is a question: “Is it a line graph or is it a scatter plot?” This argument is central to different views of mathematics and its purpose. In mathematics lessons, problems from outside of mathematics are brought in to illustrate pure mathematical ideas. They are presented as if they were real problems, but know they are not. This can infuriate the departments whose problems have been colonised in this way. For example, in a maths class, straight line graphs will be taught using examples such as this:



In maths this is done so that students can practice drawing straight line graphs. They plot the points and without any consideration for the context, they join them together. They may say that the equation of the line is something like $y = 3.4x$

Certainly in maths, this is an example of a straight line graph.

If the same thing were to happen in a science lesson the graph would look like this:



Now, since the data came from a real experiment, the points cannot lie exactly on a straight line, even if the relationship between the two variables suggests it should. We cannot measure accurately enough. So, the job is to find a line which fits the data as accurately as possible. In science this is a scatter plot with a line of best fit.

I always suggest to the maths department that the first thing they can do when trying to encourage other departments to start working in a consistent way with their mathematics and numeracy, is to go down to science and admit that mathematicians steal stuff from other subjects without really caring about it and in doing so, do damage to important features of that subject. Having said that, the mathematician, suitably humbled, is ready to say what really does matter to them.

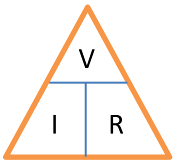
The key areas that really matter are in written algebra and in statistics. Algebra is itself a language and it must be used with great care and accuracy, so it is very important that everywhere in the school students write their numbers and letters clearly.

Importance of accuracy in algebra: examples

- 2 and 7 can easily look like Z and 1 (in Europe they cross them for clarity).
- Always write a curly x for a variable and a straight $\times$ for multiply.
- Always write a fraction as ‘over’ e.g. $\frac{2}{3}$ and never with a slash e.g. $^{2}/_{3}$. This really matters when students use fractions with algebra and is a bad habit frequently observed.
- When a calculation has more than one step, put the equals signs in a vertical line, this makes clear that something has been done, before moving to the next step:

$$\begin{aligned} 3x + 1 &= 6 \\ 3x &= 63 \\ x &= 21 \end{aligned}$$

- Finally, it is important to be clear when a shortcut trick is being used for exam purposes, for example the triangle design for resolving equations of the form $A = BC$ is fine for exams, like this:

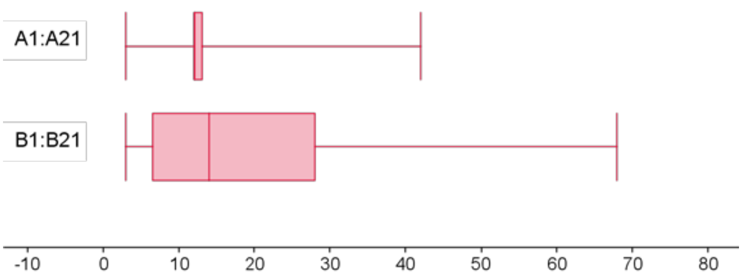


  … but is bad algebra and students really need to know that it is very limited and will NOT work with other sorts of equations (i.e. the vast majority).

There is a great deal of confusion when drawing graphs of function and charts in statistics. Most software ignores the important issues that most mathematicians feel very strongly about, so we go to great lengths to configure the software to add the things we need. You may have noticed that neither of my graphs above had a title. In maths, this is a very bad thing. However, I did set it up to put labels on the axes (important) and it automatically adds arrows to the ends of the axes (important). Regrettably, it puts two zeros at the crossing point of the axes (the origin) where one would be better. Finally, it defaults to marking points with a dot, when a cross is much better as it shows the exact position more clearly. All of these things apply strongly with statistical charts and here software is extremely variable. Those pretty 3D charts that Excel is so fond of are strictly frowned on by mathematicians. And then we have that thorny problem of ‘when is a barchart a barchart and when is it a histogram?’

In the end, this is horses for courses. Journalists and business people use natty 3D statistical charts because they are visually pleasing and create impact. However, this is the opposite of good statistics. So, my suggestion would be that those departments who make use of charts and graphs, get together with the maths department and come to an agreement about what it is important to be consistent about and how these things should be done. It is no good teaching students that something is terribly important in maths if it is of no consequence everywhere it is applied. Equally, these things are most often seen when used as a means of communication, so this must be honestly dealt with too.

Given the caveats above, a very credible policy would be to specify a single piece of software to be used in the creation of mathematical charts and graphs. It could be that one department takes responsibility for configuring the setup options to take account of the issues I have raised above but, if this software is always used, then a consistency of practice will necessarily emerge. Happily there is an excellent piece of open-source (free) software called GeoGebra (see: www.geogebra.org). It has recently been updated to include a large range of statistics tools and will soon include data-logging facilities that will delight the science department. I used GeoGebra to produce the graphs above and it will quickly generate the full range of mathematical output in geometry, algebra, statistics and number work. The box ??(5) on page ?? gives an example, produced quickly, to show two side-by-side box-and-whisker plots (the maths department will persuade all users of statistics that this is the only way to compare two sets of data).



Curiously, in maths syllabi, students are taught to draw in certain three dimensional projections and to draw plans and elevations. However, there is no expertise in maths for doing this and hence the real experts in design and technology should be brought in to show how this should be done, and the artists should engage properly with 3D, perspective, vanishing points and all.

3. Collaboration Across Departments

The best scenario regarding collaboration across departments, is that when statistics or functions and graphs are to be used, the maths department and the department needing the statistics to be used, get together and jointly plan the work. We then have a genuine possibility for mathematical modelling. The problem is framed within the subject (where they care about the outcomes and have a good feel for what counts as a valid outcome), they work together to collect the data and pass it to the maths department. There the statistics are calculated and the charts drawn or the graphs drawn and the functions fitted and the results passed back for validation, analysis and development.

Case examples: collaboration across departments

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This will allow calculation of the volume to surface area ratio for different huddling patterns and students can investigate when this is at a minimum (the smallest area of exposed penguin for the number of penguins in the huddle). The results of this analysis can then be taken back to the biology lesson to see if penguins do actually huddle as the maths suggests they will (which they do). If more time is available, the model can be critiqued (penguins after all are not made up of two cubes) and the model developed. A search on the internet (for example, http://bit.ly/HeKRhq) will show how well developed this thinking is. Having created the connection, a good part of the maths curriculum could be engaged with on this one activity.

Another example that I have used with students is for the maths department to work with the design-technology textiles department (and with RE and other humanities) and look at Islamic patterns. In maths, the principal analysis is to look at different tessellations of the plain. A visit to any mosque should allow for finding one example each of the 17 unique tessellations of the plain (different tiling patterns using only a set number of different basic shapes). The mathematics to prove that there are exactly 17 is appropriate for postgraduate level, but there is plenty of geometry in deciding and proving which shapes tessellate. Also, deciding how to organise the dividing up of basic tile shapes is rich in mathematical relationships. When the maths department had finished their analysis, the students' work was taken to textiles and beautiful prints were made. A very satisfying outcome. The excellent Islamic geometric patterns by Eric Broug (2008) acts as a detailed manual.

Some degree of curriculum synchronisation is often necessary to facilitate working in this way. Identifying the key issues where one subject needs some maths not taught at that point necessitates heads of department getting together with timetables and a spirit of compromise in hand. The best example for me is the need of science departments to draw straight-line graphs with large values long before this would normally be taught in maths. However, once together in this discussion, identifying those areas where sophisticated maths is used in other subject areas and where collaborative working would improve the consistency and quality of the maths and the quality of the outcomes would be a key benefit. For the maths department, the emphasis on using and applying and the development of functional skills necessitates finding credible and purposeful applications and the maths department stands to benefit substantially from an ability to compromise on ordering and sequencing in the scheme of work.

An effective development of policy and transition into practice needs buy-in from the senior leadership team, one of whom would certainly need to be represented on a working group, mainly composed of those key heads of department, which should be seen as an essential starting point. I have outlined three main areas of focus for numeracy cross curricula priorities. Engaging all staff with the need to be consistently supportive of numeracy especially mental numeracy development, including a calculator use policy should be seen as the first priority. I would recommend a whole school inset session, planned by the working group, but led by the maths department, would kick start the enactment of the policy. Review and monitoring by SLT and through the working group would lead up to a second whole school inset to review, practice and renew the support and response to numeracy development. The working group by this stage would have agreed the second priority, being a consistent approach to mathematics, which could be launched as a document at the second inset at the start of the second year. The second year priority for the working group would be to develop a properly integrated approach to problem solving, which would be enacted at department level. Trialling exemplar activities throughout the second year would enable a full launch of integrated cross curricula problem solving, in the third year of the policy.

Teachers' planning

The aim of this policy is to develop a fully integrated approach to problem solving across curricula. This will develop a mathematics-rich environment within all classrooms. Where a rich problem are being worked on in one subject area, and numeracy and mathematics will feature as a significant component, then this will be identified as a key activity for the type of collaborative working and joint planning that I have outlined in the examples above. The existence of the working group will ensure that timing and logistics are dealt with at department level, leaving individual teachers to develop their subject specific components of the problem solving process.
For students to buy in to rich problem solving, the settings need to be credible and accurate. We run a project collaborating with the science and business studies departments looking at the issues involved in setting up a pizza business. When looking at cooling times, we use real pizzas and practical materials to design and build pizza packaging. The smell of a hot pizza in the classroom certainly draws students into the problem as credible and believable. Teachers should always look to develop problems-to-be-solved using the physical and practical materials and equipment which as closely as possible mirrors the situation being simulated.
In all practical settings, ICT will form a dominant part of the problem solving process. Computer aided design software (CAD/CAM) will be used to develop design drawings. Spreadsheet and accounting software will be used in financial planning and modelling. Data streaming and logging software and equipment will be used in scientific experimental data collection. These should be seen as part of the equipment package with which real problems are solved and hence they should be used in the same way. I have discussed GeoGebra as a multi-purpose open source tool, which allows the possibility to engage with a wide range of mathematics, notably graphing and statistics which are exactly the areas where cross-curricula collaboration is most likely and hence developing its use in a range of departments (notably maths, science and humanities) would support a consistent approach.

Core resources

The production of a booklet showing the key issues raised within the working group for consistent responses to numeracy development and consistent mathematics, included number skills, algebraic symbolism, charts and graphs and a comprehensive list of core vocabulary is a key task of implementing the policy. Once agreed various elements should be made available as classroom posters and as a reference page in school diaries. Also, where the school has an effective virtual learning environment (VLE) or intranet, there needs to be a highly visible area showing details of the agreed practices.

One of the clearest areas in which cross-curricula working is very well supported, but still not yet particularly well implemented is in STEM. Integrating science, technology, engineering and mathematics is clear in the industrial and technological worlds, but still hard to achieve with existing subject separations in secondary schools. The National STEM Centre (www.nationalstemcentre.org.uk) provides a very comprehensive library of resources and should be seen as the first port of call within STEM subjects. The Millennium Mathematics Project at the University of Cambridge provides a range of resources which would be of importance to cross-curricula numeracy. Notably, the NRich site is the most comprehensive collection of maths problems-to-be-solved and now includes a special STEM section, but many problems incorporate possibilities for other departments (nrich.maths.org). There is also a comprehensive dictionary (thesaurus.maths.org) which is ideal for compiling vocabulary lists.

Finally the Association of Teachers of Mathematics develops a very wide range of support materials (www.atm.org.uk), while the mathematical association has excellent reports and discussion (www.m-a.org.uk). In both cases, maths departments should be encouraged to join to gain access to the association's journal and the libraries of past articles. Members will find a vast range of cross-curricula problems and discussion of cross-curricula working.

Assessment matters

It will be necessary to assess firstly the effectiveness of the policy and secondly, student's progress. The working group will need to develop mechanisms to engage with the policy, but this will need to happen at departmental level. Subject heads can feed back to the group on the extent to which teachers are able to respond consistently to the use of numeracy in their subject lessons. The effectiveness of this policy in developing student's numeracy skills can be assessed within mathematics, as these skills are being assessed their anyway. It should be possible to compare levels of numeracy skills before and after the enactment of the policy to look for some added value from it.

The extent to which the use of particular mathematical skills by students in subjects other than maths can be assessed in those subjects is a complex issue. However, it should be seen as a goal of full collaborative, cross-curricula working. As the working group identifies cross curricula problems to be solved, they will need to be planned and incorporated into departmental schemes of work. A key component of the planning will be to identify assessable curricula items within the outcomes of the problem solving process. The list of assessable items will contain items from all of the departmental curricula involved. Hence, for example, elements from maths, science and humanities would all be assessable. In the joint planning process, teachers can share how they would identify outcomes in their subject area, so, for example, if maths skills were evidenced in activity in a humanities lesson, these could be assessed and recorded by the teacher of humanities. This necessitates a cross-curricula approach to recording of assessments, which is made possible with VLEs and school data management systems. However, it requires a high level of collaboration between departments and may not be possible in the early phase of implementation.

Powerful Maths

Becoming comfortable with number relationships allows students to see patterns and relationships in all areas:

- as scientists they can see connections between variables in experiments
- in humanities they will question and explore relationships between key phenomenological variables, such as the change in weather patterns over time
- in English they can engage with the different textual analysis models used to determine issues of readability.

Maths can be very scary, but only if we are focussed on closed questions and one correct answer. Calculations are supportive of problem solving, not an end in themselves, so it is important that students choose the correct tool (brain, calculator, software) and develop their skills, consistently and in a supportive environment, across the whole school.

As curriculum manager, to facilitate departments working together to be mutually supportive of numeracy across the curriculum involves paying attention to three key strands of practice. You need to recognise that:

- mental number skills are important and that learners should be encouraged and supported to use mental methods everywhere number problems crop up – this involves a consistent approach to the use of (and often denial of permission to use) calculators
- different departments use mathematical elements in different ways, but that simply because they are different does not make them wrong; an agreement on what is important enough to ensure consistency and an engagement with the reasons for difference is needed – software such as GeoGebra provides an information communications technology (ICT) possibility to develop consistency by a policy of cross-school use
- developing rich problem-solving, taking account of the expertise in each department, by working collaboratively, is the best route to whole-school numeracy development.

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Chris has worked for many years as teacher, head of mathematics and teacher educator in comprehensive schools in London and East Africa. Having set up a Numeracy Across the Curriculum policy and practice while head of maths, he has subsequently run national sessions to heads of maths and SLT members on this and many other topics. He currently divides his time between teacher education at King's and running The Maths Zone, a maths education publisher, consultancy and innovative maths teaching materials shop based in South East London.

You can follow Chris's blog at: www.themathszone.com

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