ONE SMALL STEP FOR A PUPIL - ONE GIANT LEAP FOR CITIZENS

James NICHOLSON, Jim RIDGWAY and Sean McCUSKER
SMART Centre, Durham University, UK

ABSTRACT

OECD has launched its Global Project that aims to develop new measures of the nature and progress of societies and to increase the capability of citizens to understand and use this information. We contend that this needs to be accompanied by a developing programme at school level to equip the next generation to understand relationships in complex data.

This paper looks at the current uses of data within the UK curriculum and identifies some barriers to change. We show examples of tasks which offer opportunities for students to work with real, relevant, complex data in ways which develop sought after generic employment skills, such as collaborative working, communication and integration of ICT skills.

We believe that this research has important implications for the statistical literacy of both the next generation of citizens and the current adult population.

INTRODUCTION

Statistical literacy has been an issue of concern for an important minority for some time, but recently a number of very important players on the world stage have become actively involved in initiatives relating to it. For example, the Organisation for Economic Co-operation and Development (*OECD*) has launched its Global Project (GP) (see Giovannini (2008) for a fuller description), that aims to:

- Strengthen democracy by engaging more citizens in decisions about what constitutes social progress;
- Change cultures, so that citizens and policy makers pay attention to multiple dimensions of progress;
- Improve citizens' statistical literacy, and knowledge, so that they can understand the realities in which they live.

There are a number of barriers to the GP that include *inter alia*: low levels of statistical literacy in the adult population; school curriculums that do not address evidence-based decisions or real-world data; and the credibility of official data sources in public eyes. If ambitions to strengthen democracy through such changes are to succeed they require the next generation to be educated to understand relationships in complex data. We will provide an overview of the current statistics curriculum within compulsory education in the UK and identify some barriers to progress as well as reporting on some work that offers hope.

STATISTICS CURRICULUM IN THE UK

Broadly speaking, statistics and probability make up approximately 20% of the compulsory curriculum in mathematics for pupils aged 5 – 16, in a strand titled Handling Data. At age 16, almost all pupils enter a high-stakes examination (GCSE) in mathematics. A Grade A*, A, B or C in mathematics (and in English) is a normally a requirement for entry into any university education course or to any professional or semi-professional occupation.

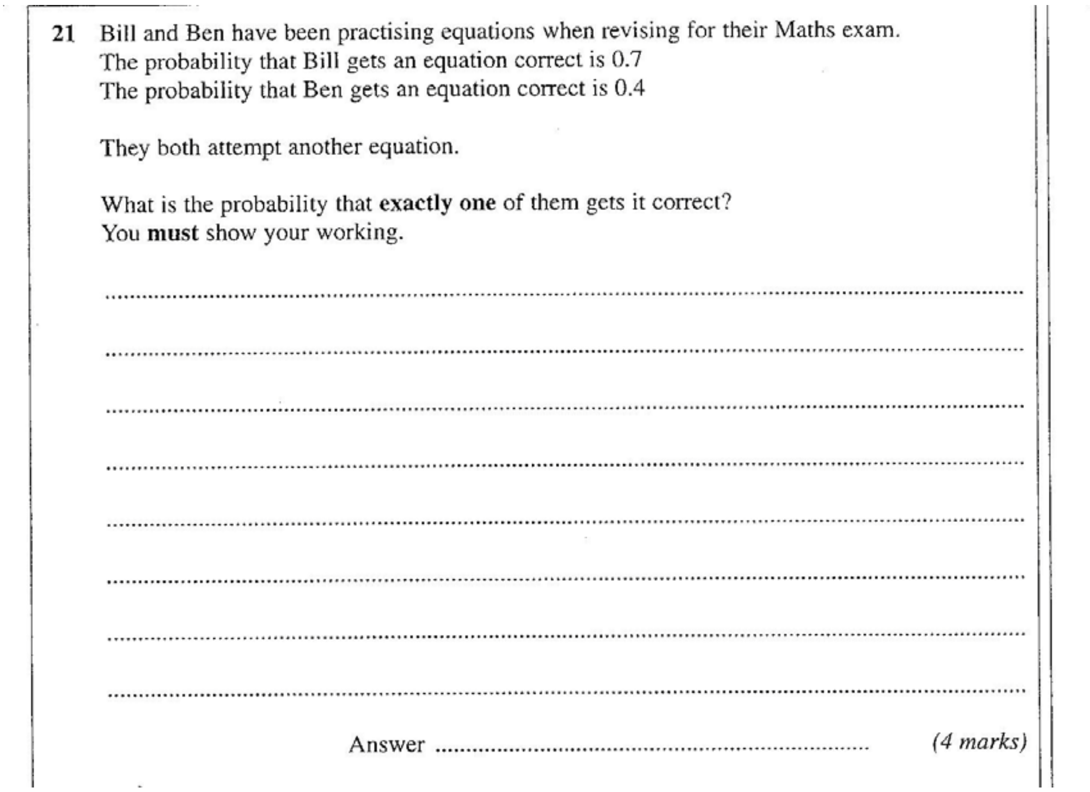
The major topics covered in this curriculum take probability up to the level of tree diagrams and conditional probability, graphical representations and summary statistical measures, not including standard deviation, and the basic ideas of sampling, including simple, random, and stratified samples.

Assessment is a major driver in determining the curriculum experienced by many pupils in classrooms. Swan (2005) identifies weaknesses in the assessment of mathematics generally where he argues that the most able students understand that they have to leave their knowledge of the way things work in the real world at the door of the examination hall in order to do well. Table 1 shows an analysis of the statistics items in all the GCSE papers in the summer of 2008 (there are three awarding bodies in England, namely AQA, Edexcel and OCR). The examination is available at 2 tiers of entry – Higher Tier gives access to grades A* to D and Foundation Tier accesses grades C to G. For each awarding body, there are some questions common to both tiers to enable grade standardisation to take place.

Table 1: the proportion of marks awarded for understanding or interpretation in statistics questions appearing in GCSE papers in the summer of 2008.

Awarding body	AQA	Edexcel	OCR
Higher tier	11%	8%	21%
Foundation tier	12%	3%	21%

Most of the available credit was for performing routine computations, requiring little understanding or interpretation of data. Often data were used with no context attached, or with no use made of the context at all. Moreover, there were instances in which using contextual reasoning would lead to an incorrect answer (‘incorrect’ in the sense of not agreeing with the published solution of the examiner). Figures 1 and 2 give examples of these, and a more detailed analysis of more examples is available at www.dur.ac.uk/smart.centre/ publications.


21 Bill and Ben have been practising equations when revising for their Maths exam.
The probability that Bill gets an equation correct is 0.7
The probability that Ben gets an equation correct is 0.4

They both attempt another equation.

What is the probability that **exactly one** of them gets it correct?
You **must** show your working.

Answer .... *(4 marks)*

Figure 1: an example of a poor question where the context gets in the way

The context of the question in figure 1, of Bill and Ben practicing equations, to assess combining probabilities is very poor. The published answer (0.54) requires the student to assume that the probabilities are independent. Independence would require Ben to get right 40% of the equations that Bill got wrong, but the questions Bill gets wrong are likely to include most of the hard equations. The correct answer should be ‘between 0.3 and 0.54’.

22 A mobile speed camera recorded the speed of some vehicles on a motorway.
The table shows the results.

Speed, s (mph)	Frequency
$0 < s \leqslant 30$	42
$30 < s \leqslant 50$	54
$50 < s \leqslant 60$	82
$60 < s \leqslant 70$	116
$70 < s \leqslant 80$	70
$80 < s \leqslant 120$	36
Total	400

22 (a) Draw a histogram to illustrate the data.

22 (b) Drivers of vehicles doing more than 77 miles per hour were given a speeding ticket.

Estimate the number of drivers who receive a ticket.

Figure 2: an example of a poor question on interpreting graphs

In the question in figure 2, the histogram in part (a) identifies a rate of 7 drivers per mph between 70 and 80 and a rate of 0.9 drivers per mph between 80 and 90 and the required answer to the question is 21 + 36 = 57 (56 – 58 is the acceptable range to be awarded the single mark available for this part question). The appropriate statistical diagram to answer part b would be a cumulative frequency curve, where the behavior across the continuum may more reasonably be inferred.

Cobb and Moore (1997) say that data are numbers with a context, so we looked at how many of the questions had a context, and then how many made use of the context in any real sense. The results are summarized in table 2.

Awarding body	AQA	Edexcel	OCR
Number of questions on statistics	12	13	10
Number of questions with a context	7	9	8
Number of questions in which context is used	3	4	5

Table 2: analysis of contexts in statistics questions appearing in GCSE papers in the summer of 2008.

Figure 3 shows an example of a question which has a context, but no use is made of the context at all. The candidates are required to draw a frequency polygon, but do nothing more (and incidentally are expected not to notice that the first interval is not the same size as the others).

8. 60 students take a science test.
The test is marked out of 50.

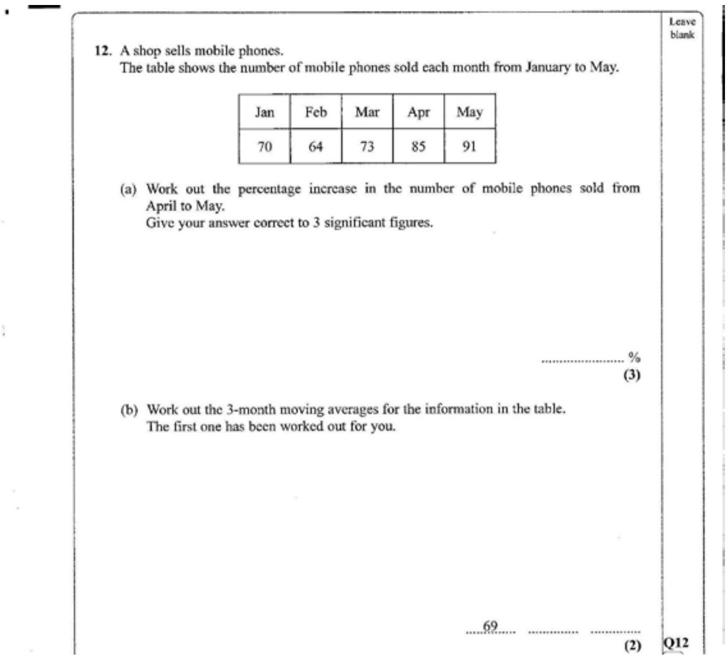
This table shows information about the students' marks.

Science mark	0–10	11–20	21–30	31–40	41–50
Frequency	4	13	17	19	7

On the grid, draw a frequency polygon to show this information.

Figure 3: an example of a question with a context which is not used.

Figure 4 gives data on mobile phone sales and candidates have to work out a percentage increase from one month to the next, but do nothing more with this, and to calculate two more 3-month moving averages, having been given the value of the first. No reason for calculating moving averages, or the appropriateness of a 3-month average, is given or asked for, and nothing is done with the three moving averages.


Leave blank

12. A shop sells mobile phones.
The table shows the number of mobile phones sold each month from January to May.

Jan	Feb	Mar	Apr	May
70	64	73	85	91

(a) Work out the percentage increase in the number of mobile phones sold from April to May.
Give your answer correct to 3 significant figures.

.... %
(3)

(b) Work out the 3-month moving averages for the information in the table.
The first one has been worked out for you.

....69.... ....
(2)

Q12

Figure 4: an example of question where the context is not used appropriately.

The message which comes from such assessment practices is that statistics is about trivia, you have to be able to carry out calculations and draw graphs even though no use is going to be made of these outputs to make a decision or make a comparison, or to develop an understanding of the current situation in which data has been collected. In some cases it would be reasonable to ask whether anyone in the world would actually be interested in the answer to this calculation, and the problem is exacerbated by examiners using completely inappropriate models of situations such as in figure 1.

Many textbooks in popular use take their lead from the style of assessment pupils will encounter in these examinations. Often a new technique will be demonstrated by a set of data in no context, and little explanation given of what makes this technique useful, or different to other possible approaches. For example, in introducing stratified sampling, most textbooks describe it (accurately) as producing a representative sample, but without any indication that the consequence of this is that estimates based on a stratified sample (provided that the quantity of interest varies between strata) will be more consistently close to the population mean than those based on simple random samples – that a major source of variation has been removed by using a representative sample. Any question with a numerical answer will have that answer supplied, but often questions requiring a discursive or interpretative answer will not – not even an indicator of the things which might be expected to be included in an answer.

A major obstacle to improving the assessment of statistics in these examinations is that it can not require the use of a computer, so automating graphical displays and calculations, working with large data sets, or simulations, or new data interfaces with complex data are not possible. Instead a substantial part of the assessment is still devoted to producing by hand techniques which are automated in working practice.

CURRICULUM REFORM IN THE UK

New curriculums being introduced in the UK have ambitions to develop some of the ‘soft skills’ which employers feel are important in the modern workplace, but which new employees are weak in. These include communication, collaborative working, and the use of Information and Communications Technology (ICT) as an integral part of many tasks. These ‘soft skills’ are actually about ways of working and therefore very difficult to teach directly, and are also difficult to assess directly. In mathematics, group work is often imposed on activities which might be regarded as hard for a particular class on the basis that it should be more accessible in a group. In reality, this rarely leads to the sort of collaborative working valued in employment where all members of a team take some responsibility for part of the work, and make a contribution to the overall effort. Rather, the group dynamic will often be that the most able person is expected to solve the problem, with others perhaps making suggestions which may help them towards the solution. ICT is rarely an integral part of the task in the sense employers mean, which is much more than using ICT to produce a graphical display, or a word-processed report. The use of the internet to research information is one aspect which is now common to school and to the workplace, but otherwise the use of ICT to do something which simply could not be done otherwise is rare.

Curriculum areas like citizenship, geography and science deal with contexts where multiple factors interact, but up to now they have not been able to make substantive use of data because 4 or 5 way tables are much too difficult for pupils to make sense of. The use of new interfaces, such as Gapminder and those developed by the SMART Centre now allow the visualization of complex data in ways that allow even relatively young pupils to identify relationships between multiple variables (Ridgway *et al*. in press a).

Introducing the use of these interfaces in these subject areas has had some success because it allows teachers access to a dimension of the subject area which was not previously available. The usefulness is inherent, in building up understanding of complex contexts, so even though the assessment in these subjects does not permit the use of technology either, the discussion which its use stimulates in the classroom is viewed by some teachers as offering an additional string to their teaching bow – not that it revolutionizes their classroom, but that it can enhance it.

PUPILS AS CITIZENS

The documents outlining the statutory requirements for citizenship in schools for pupils aged 11 – 16, contains the statement in figure 5 when identifying the importance of citizenship in the curriculum (Downloaded 27 January 2009 from http://curriculum.qca.org.uk/key-stages-3-and-4/subjects/citizenship/index.aspx)

> Citizenship addresses issues relating to social justice, human rights, community cohesion and global interdependence, and encourages students to challenge injustice, inequalities and discrimination. It helps young people to develop their critical skills, consider a wide range of political, social, ethical and moral problems, and explore opinions and ideas other than their own. They evaluate information, make informed judgements and reflect on the consequences of their actions now and in the future. They learn to argue a case on behalf of others as well as themselves and speak out on issues of concern.

Figure 5: statement from the citizenship curriculum in the UK

Developing activities which genuinely allow pupils of the full ability range to engage with such issues is not trivial. Ridgway *et al.* (in press b) shows how pupils aged 13-16 years can engage with public discussions about the world, theories and recommendations in the media and about what political actions ought to be taken, based on multivariate data from official sources. A mashup is a webpage or application which combines information or functionality from two or more sources. Figure 6 shows the form of the mashup which students were presented with, links to news stories about young people's use and abuse of alcohol are on the left, and figure 7 shows the story in the first link (downloaded from http://news.bbc.co.uk/1/hi/health/1600322.stm on February 27, 2009). The data shown in the display (comparing drinking behaviour in 15 year old boys split by whether or not they had had lessons on alcohol abuse in school within the previous 12 months) suggests that traditional lessons relating to alcohol are not effective in changing behaviour. Using the sliders in the display confirms that the story is similar for other age groups and for girls.

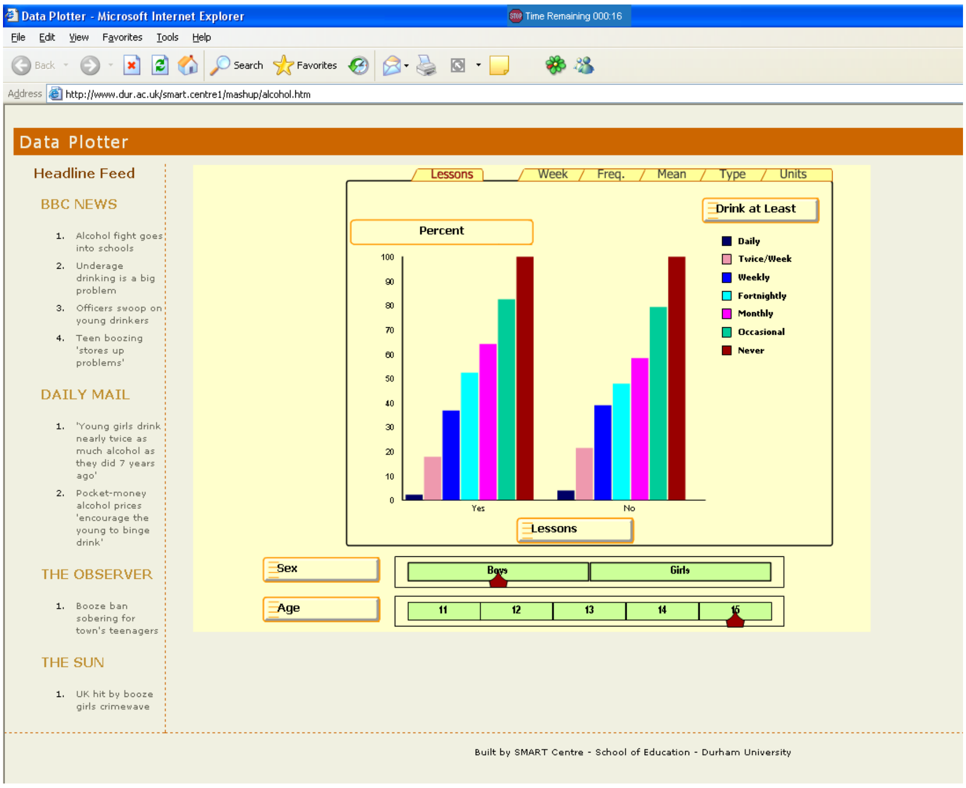


Figure 6: mashup with links to stories about alcohol use and interactive data display.

Figure 7: example of a news story in the mashup

Essentially, we have used the same data tools that allow sophisticated users to understand complex relationships, tailored for use with teachers and pupils, and embedded in rich accessible contexts, such as the use and abuse of alcohol by young people.

Critically, our initial work has taken the materials into a number of schools with very different profiles and worked with pupils across a wide range of academic ability, and understanding of the key messages is accessible to pupils well below average academically (Ridgway *et al.*, in press b). Moreover, student self-reporting of engagement with the materials was high across the ability range. Teacher informal evaluation of pupil engagement was that all students found the materials engaging, where often the level of engagement with standard mathematics activities is strongly correlated with ability in mathematics.

The other interesting anecdotal evidence from the pupils was that the data on use and abuse of alcohol made much more of an impression on them than in more traditional lessons relating to the same subject – where the pupils felt 'preached at' and statistical evidence was in the form of single fact headlines. It remains to be seen whether education on alcohol use and abuse which incorporated data exploration with these tools would be more successful in influencing behavior than the current types of lessons, but there is some reason to hope that it might have some impact.

DISCUSSION

Many mathematics and statistics classrooms are characterized by a didactical contract based on a transmission model of teaching and learning. There is an established difficulty of changing methods in mid-year, but we conjecture that these activities might do that, because it is not the teacher (the controller in the didactical contract) who is instigating the change (in the perception of the pupils, whatever the reality in the sense that the teacher has introduced this activity) – it is that the activity itself drives a different dynamic in the classroom. Even those who do not feel comfortable with mathematics seem very quickly to go beyond the maths and just engage with the contextual information and what it says. Often they also speculate why what they see in the data might be happening.

We believe that students should be shown the power of statistics in answering questions they are actually interested in, and should see the use of statistics to empower them in a range of situations (following Vygotsky). Unsurprisingly, we have little sympathy for curriculums that make extensive use of technical exercises based on toy data.

We are interested in the conceptions students bring to complex problems, the languages they use (including gestures, diagrams and neologisms), their constructions and co-constructions of meaning and the ways that prior ideas shape explanations of data, and ideas on actions that might be taken, based on the evidence available. We are interested in the links between theories of phenomena, possible courses of action, and data interpretation. For example, can students distinguish between theories about phenomena (*x* causes *y*) and empirical observations (when *x* goes up, *y* goes up)?

In terms of theoretical assumptions, we could be described as constructivists, social constructivists, and even radical constructivists (we are interested in students inventing statistical ideas and methods). We believe that curriculums that start with one- and two-sample problems, then building up to anova and beyond, actually *create* conceptual problems that would not arise if students worked with multivariate contexts at an early stage in their statistical development.

We believe that the definition of 'statistical reasoning' needs to be reconsidered. Topics that are conventionally considered to be advanced statistical ideas, such as the interpretation of interactions between multiple variables, non-linear relationships between variables, including limiting values on variables ['if it is too cold or too hot, there is no plant growth; between 2 particular temperatures, growth steadily increases with temperature to some maximum point, then steadily decreases], should be part of 'statistical literacy'. We also believe that there needs to be a rebalance of the emphasis placed on some topics; in particular, statistical significance is over emphasised; and effect size and confidence intervals are underemphasised, in many programmes.

Many students and teachers are able to work effectively with complex multivariate data presented in a mash-up, and we believe that the current curriculum seriously underestimates the extent to which students can reason with complex evidence. Pupils seem to regard working with these interfaces as a small step, but engaging with and making sense of complex evidence represents a giant step for citizens.

REFERENCES

Cobb, G.W., & Moore, D.S. (1997). Mathematics, statistics and teaching. *American Mathematics Monthly, 104. 801 - 823*

Giovannini, E. (2008). The Role of Communication in Transforming Statistics into Knowledge. Proceedings of the OECD Seminar on Innovative Approaches to turning Statistics into Knowledge. Stocholm, Sweden, 2008. http://www.oecd.org/dataoecd/30/32/40293021.pdf

Ridgway, J., Nicholson, J. R., & McCusker, S (in press) Alcohol and a Mash-up: Assessing Student Understanding

Swan, M.B., 2005. *Improving learning in mathematics: challenges and strategies*. Department for Education and Skills, London, UK