# REASONING WITH EVIDENCE – DEVELOPING CURRICULUM

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*Reasoning from multivariate evidence is pervasive in political speeches and in the media, but is largely absent in UK schools. Currently, we do not prepare young people to understand important social debates, nor to make informed decisions about their personal well-being. We have evidence that students can work with multivariate data if supported appropriately with technology, and are working with teachers of mathematics, citizenship, and geography to develop curriculum materials designed to develop an understanding of complex issues in the curriculum, and reasoning from evidence in general. Examples of the use of survey data on sexually transmitted diseases, which students explore using powerful interfaces, are shown to illustrate our approach.*

## INTRODUCTION

Real-world problems have a number of features: data are multivariate; relationships are rarely linear; 'systems' must be considered where multiple variables interact in multiple ways; feedback is common. Reasoning with data is pervasive in political speeches, and in the media, and its importance as a life skill is increasing. In the United Kingdom (UK), the current National Curriculum presents very few opportunities for students to engage with complex data and the current statistics curriculum does not prepare our young people to understand important social debates, or to function effectively in their personal lives (Nicholson, Ridgway and McCusker, 2006).

Here, we report work on two parallel developments:

- The development of tools and curriculum materials to support reasoning from complex data, with applications in two different curriculum subjects;
- Work to understand the development of students' knowledge about reasoning from complex data, as they work in ICT-rich environments.

We are assembling a number of components which have the potential for a transformative effect on teaching and learning. Traditionally, access to large data sets has been impossible; powerful analytic tools have been expensive and difficult to use, and the school curriculum has focused on teaching simple analytic methods rather than teaching approaches to understanding complex situations using computer-based tools. Here, we invert the traditional approach of learning about statistics by considering very simple situations used to illustrate technique; rather, we start with understanding complex situations where statistics can help.

We are working with teacher groups in geography and citizenship, to identify rich and relevant data sets that illuminate key curriculum themes and to identify effective pedagogical approaches for integrating them into the broader curriculum. Traditionally the UK curriculum from ages 11 to 16 is organised and taught in discrete subject areas, and there has been little coordination or cooperation across subject boundaries. Effective cross-curriculum materials are not widely available. The primary use of the materials from this project will initially be in subject areas outside mathematics, but we are developing parallel materials for use in mathematics to enable a coordinated cross-curricular approach to be taken.

## CURRICULUM BACKGROUND

A very high proportion of the assessment in the UK high-stakes qualifications at age 18 years rewards procedural competence and a correspondingly low proportion rewards interpretation or modelling. Moreover, students never work with more than 2 variables at a time, and when they work with two variables, relationships are always linear (Ridgway, Nicholson and McCusker, in press).

'Evidence-based' policy has become a mantra across the political spectrum. However, evidence in policy arenas such as health, education and crime is invariably characterised by the sort of complexity described earlier. A problem arises for the democratic process if few people can reason from such evidence. Similarly, commerce operates in a fast-moving, complex environment, and important decisions have to be made based on incomplete information.

There are a number of curriculum areas where students are expected to reason in complex contexts, notably in citizenship, in geography and in biology amongst mainstream subjects, but also in psychology, business studies and economics, other science arenas, sociology and in history. In the main, these subjects provide opportunities to work with data, but do not *require* a data-based approach; situations are often described qualitatively which would benefit from some quantification (for example on the importance of the relative effects of different variables).

Following the publication of a report (Smith, 2004) into the teaching of mathematics from age 14 to 19 in England, which opened up a debate about the position of statistics, the Royal Statistical Society (RSS) held a roundtable meeting in July 2005 to explore issues related to *Statistics Across the Curriculum* with representatives from biology, economics and business studies, citizenship and psychology. There was a consensus about the need for improved professional development in statistics in each of the disciplines even to deliver properly the current level of statistics within each subject area's curriculum, and also concern about whether there was space in the curricula of other subjects to accommodate teaching core statistical topics. The Qualifications and Curriculum Authority (QCA) have commissioned the RSS Centre for Statistical Education to carry out a review 'to determine what of the Statistics and data handling coursework content of GCSE Mathematics should be core for mathematics and what may be beneficially seeded through other subjects.' This review entails extensive consultation within schools about the position of statistics teaching, including the readiness of teachers in other subjects to take on any extra responsibility for teaching statistics.

Statistical literacy has been of growing interest both in society and in the education systems for our young people over the past 20 years. Various efforts have been made to describe the requirements for people to be able to participate fully in society. These have included the capacity to interpret statistical information, presented graphically, in tables or in words and to have some critical appreciation of whether certain conclusions can be justified by the information available. If statistical literacy is to be introduced into the school curriculum, there needs to be an understanding of the nature of the statistical concepts required, and of the logical dependencies between them. Watson and Callingham (2003) have done some important initial work on developing such a hierarchy, based on Rasch analysis of responses to items by over 3500 students across grades 3 to 10 in Australia. Their analysis looked at items based on areas of statistical reasoning and literacy which are found in traditional curricula: average and chance; sampling and inference; and the representation of data and variation. There are two areas of interest which the Watson – Callingham studies do not address, namely reasoning with more complex data and the use of ICT to reason from evidence. We believe that both of these areas are important.

We have evidence from our own work (Ridgway and McCusker, 2003; Ridgway, McCusker and Nicholson, 2004) that digital technologies make it easier for people to reason with data – to help them visualise, describe and tell plausible stories about data. There is a widespread dissatisfaction with the way that evidence is presented in the media (and in government documents). Huge data sets relevant to human lives are available on the web (e.g., from the World Health Organisation), but the interfaces are poor. Reasoning about situations is a minority sport; modelling is an orphan in the school curriculum and in the media.

For people to take control of their lives, they need access to appropriate evidence and models, and the ability to reason from that evidence so as to inform their behaviour. The key features of this approach are:

- Constructivist learning is encouraged by user control over what is presented;
- Students work with multivariate data, so that phenomena are not trivialized;
- There is an emphasis on qualitative understanding of complex phenomena before any quantitative analysis is done (spurious and/or naïve quantification will be avoided).

We are working with teacher groups to incorporate these affordances in some curriculum materials, notably in the domains of citizenship and geography.

CITIZENSHIP

We have started to work with a small group of citizenship and mathematics specialist teachers in schools near Durham to develop classroom resources to support reasoning with data. The statutory programme of study [PoS] shows opportunities for a data rich approach as well as other approaches which may not use quantitative reasoning at all, with a single exception at Key Stage 4 (age 14 -16) which lists 'an awareness of the use and abuse of statistics.' Citizenship co-ordinators have very varied roles: sometimes they are strategic co-ordinators, but more often are the actual teacher of citizenship. Although citizenship is now statutory, the quality of delivery is highly variable. Many schools teach citizenship alongside other subjects, or identify areas of other subjects which are 'citizenship related'; however citizenship must be made explicit in lessons, if teaching is to satisfy statutory requirements.

A striking feature of the initial meetings with teachers was how strongly they felt about the need for materials which were genuinely relevant to the main issues facing the pupils in their schools, and in the deprived areas round Durham. These included teenage pregnancies and sexually transmitted infections [STIs]. In particular, they wanted access to resources which explore the infection rates for different categories of risk behaviour, such as the level of sexual activity, age of first sexual encounter, use of condoms, social class etc. Other topics of interest to students which lend themselves to using rich data resources include: road traffic accidents; obesity; crime; and bullying. In the past few years there seems to have been a shift in teachers' attitudes, driven by the necessity of addressing problems with the potential to blight their students' lives, which has overcome inhibitions in dealing with such sensitive issues as STIs.

Relatively high rates of teenage conception and sexually transmitted infection among young people in Britain have focused attention on early sexual behaviour and its determinants. The second National Survey of Sexual Attitudes and Lifestyles (NATSAL 2000) was a large scale study with 11,161 men and women aged 16 – 44 years in Britain, interviewed between 1999 and 2001, using a combination of computer-assisted face-to-face and self-completion questionnaires. Wellings *et al*. (2001) assert that factors relating to early sexual behaviour which are most strongly associated with risk behaviour and adverse outcomes have considerable potential for preventative intervention. NATSAL 2000 contains a wealth of detailed information: new interfaces make it possible for students to explore the strength of factors, interactions between effects, and trends, and to identify these relationships for themselves in contrast to the current model where students are presented with a range of 'facts' about risky behaviour and its possible consequences.

There is the potential for genuine co-operation between subjects here – students do real statistics to discover relationships in data, and learn to describe the relationships, and in citizenship, or geography, the teacher can bring out key curriculum themes.

To illustrate the potential for using graphical representations to make data more accessible, consider Table 1. This is part of the simplest of 5 tables in a paper reporting on risk behaviours relating to sexual activities, in Britain (Johnson *et al*., 2001). One column of data has been highlighted – which shows the proportions of men aged between 25 and 34 having varying numbers of sexual partners in their lifetime. The original table contains overall proportions as well, and similar information for women alongside it, so a high level of sophistication would be needed to make sense of all the information in the table.

Table 1: number of partners (from NATSAL 2000)

| *Number of partners* | *Men(age group[year])* | | |
|---|---|---|---|
| | 16-24 | 25-34 | 35-44 |
| *Lifetime* | | | |
| 0 | 19.6% | 3.5% | 1.8% |
| 1 | 14.9% | 8.4% | 10.7% |
| 2 | 8.2% | 7.2% | 7.2% |
| 3-4 | 16.6% | 14.3% | 13.4% |
| 5-9 | 21.0% | 25.2% | 28.3% |
| 10+ | 19.7% | 41.4% | 38.7% |
| *Past 5 years* | | | |
| 0 | 20.6% | 5.2% | 4.4% |
| 1 | 17.2% | 39.4% | 64.7% |
| 2 | 10.5% | 14.0% | 11.2% |
| 3-4 | 18.2% | 17.2% | 10.6% |
| 5-9 | 19.5% | 14.6% | 6.2% |
| 10+ | 14.1% | 9.6% | 2.9% |

The same information can be seen graphically in Figure 1. The horizontal axis shows the various numbers of sexual partners the data was grouped by, but there are also two sliders which currently set to the 25 – 34 age group and the lifetime number of partners. The visual representation, with the capacity to see how trends change for different groups is much more accessible than the same information contained in Table 1.

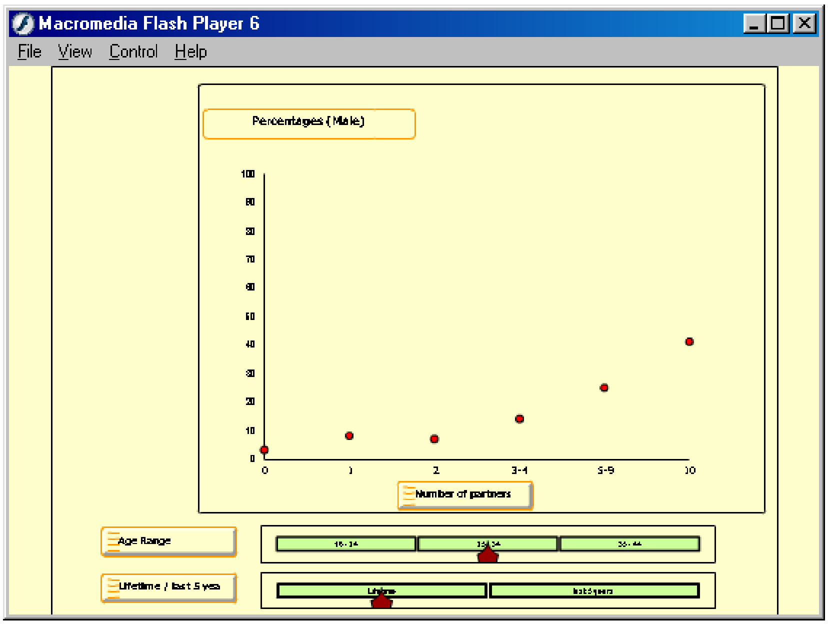


Figure 1: Graphical display of number of partners (from NATSAL 2000)

An area for future exploration is the number of variables which students can handle – this interface has one response variable and three explanatory variables, one on the horizontal scale and two others shown on sliders. It can easily be extended to show a fourth, such as sex (via different colours), and the restriction to a dichotomous variable is not a technical one but based on the amount of information which can be visually assimilated at one time. An interesting question arises as to whether students could be presented with more possible explanatory variables than the interface will display at once, and still be able to make sense of this greater degree of complexity.

Initially it seems that with a dynamic display, it is easier to visually track changes in values with dots rather than with the more conventional column chart representation. This is an area which warrants further investigation, especially when a 4th dimension is added to the axis. New data interfaces may well require a new set of conventions.

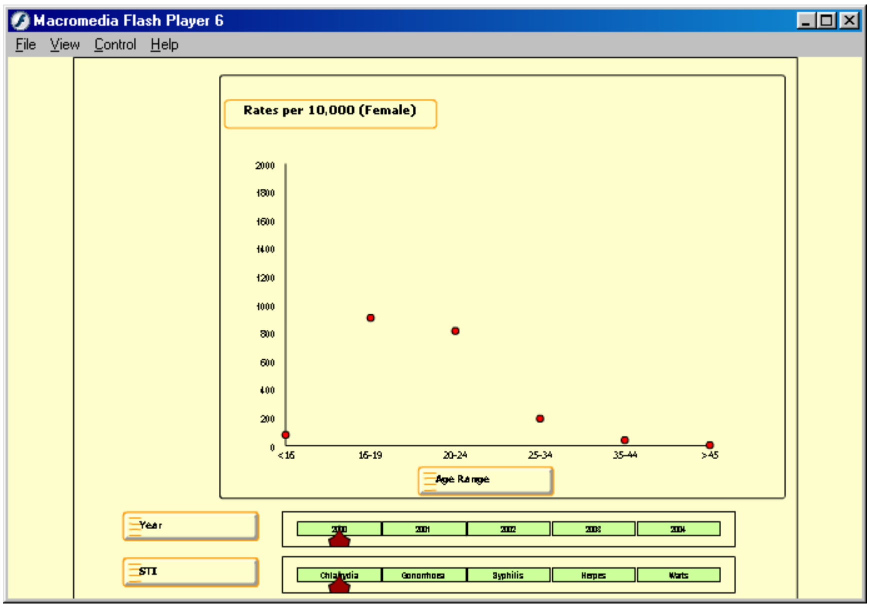


Figure 2: Graphical interface allowing 3 explanatory variables to be explored

Figure 2 shows the rates of incidence of different STIs using the same interface. The data displayed is for chlamydia in the year 2000, for females across different age groups.

Year of Survey is on a slider, so students can explore the (dramatic) changes in the incidence of chlamydia and other STIs over a short time span. Teachers see this display of summary information as more accessible and interesting to students than tabular data, and see a lot of potential in students being able to explore different factors, and discover relationships for themselves. In particular, these displays stimulate problem solving posing by teachers and students (why is Chlamydia far more common in females than in males? Why has Chlamydia increased dramatically in 4 years while herpes has not?) and can lead to further research by students.

GEOGRAPHY

Comprehending and communicating with multivariate numerical data is increasingly important, and geography is in a good position to provide meaningful contexts in which appropriate skills can be taught. Geography seeks to uncover and possibly explain patterns and relationships in the physical and human world. Often, these are complex and far from clear cut. Geography has a long tradition of using applied statistics. Where teachers are confident and well prepared this is done well in schools, with students effectively trained in descriptive and inferential statistical techniques. Although evidence is hard to come by, it is likely that statistical geography is less prevalent than it was twenty years ago. Further, the 2005 White Paper (www.dfes.gov.uk/publications/14-19educationandskills) is critical of much of the teaching of geography at ages 11-14 years (p. 33), and so there is considerable room for improvement. In mathematics, there is a desire to show the usefulness of models in helping to understand and deal with complex situations (and very few examples exist in school mathematics!), so there is the possibility of an exciting synergy between the two disciplines. Our overall goal is to develop strategies in geography to encourage and enhance students' capacity to reason with complex data. We intend to look at ways to extend students' activity beyond simple descriptive and inferential statistics which often use just two variables, to the exclusion of real world complexity. This we believe restricts students' understanding of risk and how to judge multivariate issues – for instance, relating to disease and immunisation programmes, flooding and planning for extreme weather events, crime etc. We want to develop ways to help students to understand what numerical data can tell us and what they do not say. We believe such skills are increasingly important for informed, educated future citizens.

## DISCUSSION

The introduction of a compulsory extended statistics coursework project in the high-stakes qualifications for mathematics at age 16 in the UK in 2000 caused considerable angst for teachers and pupils. The expectation was that pupils should deal with complex data sets, yet this was outside their curriculum experience (Nicholson, 2003). There was a paucity of materials available, and no guidance for teachers as to the hierarchical structure of the skills in this area: textbooks contained almost no examples of data more complex than a linear bivariate relationship, and rarely any guidance on appropriate language to use in describing relationships, or even on strategies to use to decide whether an observed difference is sufficiently large for it to be reasonably be described as a reliable difference.

We have evidence (Ridgway, Nicholson, and McCusker, 2006) that students can deal with greater complexity in data if they have the appropriate tools and visualization support. It will take some time before we can gather evidence at to whether students better understand critical issues facing them and their world if they are better at understanding quantitative evidence, but we conjecture that this will be the case.

We are working with groups of teachers in mathematics, citizenship, and geography to develop appropriate curriculum materials, based on extensive use of ICT. The ICT component of these materials are in Flash, and therefore run in any browser such as Internet Explorer, and they can be distributed cheaply and easily. There is a great deal of work to be done to understand how reasoning from evidence develops in general, and most particularly in the context of extensive ICT support, in different curriculum subjects. A further step will be to explore the development of statistical competences across curriculum boundaries, with a view to developing appropriate resources and plans to support an integrated approach to statistics across the curriculum.

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