# LURING NON-QUANTITATIVE MAJORS INTO ADVANCED STATISTICAL REASONING (AND LURING STATISTICS EDUCATORS INTO REAL STATISTICS)

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*Introductory courses in statistics often progress from simple analysis to anova and interaction. The epistemology is close to elementary physics–simplify, decompose, analyse, then add the bits together again, and you will understand the phenomena. Most interesting problems in social sciences are multivariate, and variables interact in complex ways. Biological systems provide a better analogy–below a certain level of complexity, you destroy the problem by decomposition. The big statistical ideas in social policy are things like the shape of multidimensional data surfaces, effect sizes, interactions, limiting factors, extrapolation, and confidence intervals. Statistical significance is usually irrelevant; assumptions about distributions are risky. Non-quantitative majors are quite right to be wary of standard statistical models. We offer a plan to lure non-quantitative students into statistical reasoning by proving rich, multivariate data from large scale studies, along with media accounts (which are often simply wrong). Some 'proof of concept' will be provided.*

## INTRODUCTION

Real-world problems have a number of features that make them difficult to understand. Problems are almost always multivariate. Variables interact; there are non-linear relationships; variables often have piecewise functions over different parts of their range. Reasoning from evidence is a core life skill that is largely missing from the school curriculum, and as a consequence, students arrive at college with little or no experience of working with this sort of reasoning. One can identify a number of reasons for this lacuna:

- The subject-based nature of the school curriculum, which mitigates against collaboration, and the establishment of key core themes;
- The perceived difficulty of presenting students with complex evidence; data in the public domain (such as census data, and data from government departments) are rarely presented in a way that is accessible to students (or indeed to teachers);
- The conceptual difficulties inherent in statistical inference;
- The inappropriateness of simple statistical techniques for modelling complex phenomena;
- The absence of a tradition of working with semi-qualitative or semi-quantitative data – to oversimplify, in mathematics and science, too much time is devoted to teaching pre-defined models as if they were 'true' (in part because they have overwhelming empirical support), and in the arts and humanities there is an absence of methods for representing complex problems.

Information and Communication Technologies (ICT) provides new ways of representing multivariate data; we have evidence from a large scale project developing e-assessments that young children can understand such representations, and can use them to make reasoned choices about complex situations. Reports from teachers and students using curriculum materials incorporating these new interfaces suggest that both groups (teachers and students) are more comfortable with discussing interpretations of multivariate data where there are strong stories about real and relevant issues, than they are in trying to offer interpretations of some of the artificial data they routinely meet in many school textbooks and in high-stakes assessments in the UK (see Nicholson, Ridgway & McCusker, 2009).

We hypothesise that working with visual representations of multivariate data at an early stage would help students to develop mental models of possible relationships between multiple variables which would give them a stronger conceptual basis for considering the formal statistical analysis they will meet in courses such as psychology or geography. Perhaps more important is the

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need for courses in social science, health, political science, business and journalism to examine rich ands authentic data sets.

We will set out a rationale for including data-based explorations in core subjects such as citizenship, and in optional subjects such as psychology, sociology, politics, critical thinking and general studies which are traditionally popular choices for pupils who will take non-quantitative majors at college or university, and we will offer examples of contexts suitable for such courses and some observations about student performance in this area.

## RATIONALE FOR CURRICULUM REFORM

There were substantial developments in the gathering and analysis of statistics in the early nineteenth century as governments sought to govern more, and more effectively. There were important developments in statistics in the early twentieth century, driven by the need to improve decision making in areas such as agriculture. The development of statistical theory was shaped by the need for methods that were computationally tractable. Strong assumptions were needed, such as the Normal distribution of variables, or linear relations between variables. These models are still dominant in social sciences such as psychology, despite the computational power that is now available to free us from such strong assumptions. A second major difference between the current statistical landscape and earlier ones is the existence of high quality, large scale data sets on a vast range of topics. A third difference is the rhetoric of 'evidence-based' decision making. These important developments highlight the need to rethink reasoning from evidence in the social sciences, and the statistical tools that are most appropriate. We have argued previously (e.g., Nicholson, Ridgway & McCusker, 2006; Ridgway, Nicholson & McCusker, 2007) that the current statistics curriculum in the UK does little to prepare students to handle the complex data structures which are pervasive in the real world.

Gal (2002) identifies the ability to interpret, evaluate and communicate statistical evidence as key elements in statistical literacy. The technology revolution offers a major challenge for statistics educators to identify the appropriate vehicles to develop these key core skills in a world in which data is more accessible than ever before. Many agencies assert that their policy making processes are evidence based, but it is difficult for stakeholders to critically evaluate this assertion, or indeed whether they would reach the same conclusion on the available evidence. This opens up the possibility of developing curricula which have features of both quantitative and qualitative reasoning. Subjects like geography previously emphasised quantitative methods and required sophisticated statistical techniques because of the multivariate data involved. Current specifications across a range of curriculum areas like geography have largely moved away from quantitative methods. While we are not advocating a return to formal statistical techniques as a cornerstone of such courses, we believe that the lack of engagement with any quantitative aspects in these areas is unhelpful in the immediate understanding of the concepts under consideration, and, crucially, is a major contributing factor in inhibiting the development of skills in reasoning from evidence amongst those intending to work in social science areas. There is a further consideration: currently many good 'numerate' students do not maintain interest in the social science disciplines because they don't see any future in it for them and we believe that this represents a missed opportunity both for the students and for the social sciences community.

It is not just students for whom this is a problem: only a small proportion of teachers within the broad area of humanities and social sciences are really comfortable with using quantitative methods. In our classroom trials with interactive displays, teachers have commented that they feel more comfortable in mediating classroom discussion on informal inferences accessible through these interactive representations than working with the same data in tabular form.

One of our aspirations is to develop strategies in social science subjects which 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 relate to just two variables, to key statistical ideas such as effect size and interaction. We also 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, and especially for those who aspire to work in the areas of social science.

The visual nature of the data representation makes it very easy to identify anomalous data points. This can encourage a critical evaluation of data, even when interpreting data which is presented by authoritative sources.

## CURRICULUM DEVELOPMENT

Most social phenomena are multivariate, and involve non-linear relationships between variables. There is usually a number of potentially confounding variables, and each variable may have an effect on the phenomenon of interest over only a particular range of values. We have identified a number of subjects, and particular topics within those subjects where rich data sources are available which could be used to develop skills in reasoning from evidence.

In Citizenship the Key Stage 4 statutory programme of study (for ages 14-16 in the UK) lists *critical thinking and enquiry*, *advocacy and representation*, and *taking informed and responsible action* as the three 'key processes', and identifies *democracy and justice*, *rights and responsibilities* and *identities and diversity: living together in the UK* as the key concept areas. These key concept areas provide ample scope for data-rich activities which target particularly the first two of the three key processes, using data from the Social Trends data series produced by the Office for National Statistics (ONS).

In the UK, the school leaving age is 16, though many young people stay in some form education after age 16, and may participate in a wide range of academic or vocational qualifications. The principal route into university study is to take 2 or 3 subjects at GCE level. At GCE level (for students aged 16-19), the Psychology specifications only require formal analysis of one and two variable data. However, the influence of multiple factors is pervasive in psychology and many aspects of the course consider such contexts. One specification highlights *health and clinical psychology* and *psychology of sport and exercise* as two of the four options in applied psychology. Survey data from the NHS Information Centre (IC) provides data on child and adult obesity by age and gender, and information on health risk. The same data set includes information on physical activity by adults as a function of gender, household income, awareness of recommendations for physical activities, attitudes and barriers to exercise, trends in physical activity by children, access to PE in schools, knowledge and self perceptions of children.

The GCE Sociology specifications include the study of the sociology of health. The IC has extensive data collections on lifestyle issues such as alcohol consumption, drug misuse, smoking, contraception, physical activity, diet, diabetes and mental health. The ONS publishes *Health Statistics Quarterly*–another excellent source of contemporary evidence on a range of health-related matters. There are also units on *Culture and Identity; Families and Households*; and *Wealth, Poverty and Welfare*. Rich data are available from The ONS and from the European Social Survey on changes over time in Britain and Europe.

Some examples of our interfaces can be found at http://www.dur.ac.uk/smart.centre/freeware/ where the power of the interaction with data can be explored, but the screen shots below can illustrate some of the key ideas.

The Ireland Central Statistics Office released data in 2007 which had a number of related data sets about poverty in Ireland. Figure 1a shows the percentages of males and females aged 16 or over at risk of poverty in 2004, by their highest level of education. By moving the sliders at the bottom, the same data can be seen for 2005, and for a different measurement of poverty (where the individual is consistently in poverty). The positioning of the variables can be controlled by the user, allowing other comparisons to be investigated explicitly and Figure 1b shows the data for 2004 and 2005, just for males, and moving the bottom slider now would offer the same information for females.

The statistical release also contained breakdowns of poverty rates by nationality (native Irish and non-Irish) and by age which are also available on other tabs in the interface but not illustrated here, and broken down by household composition, which is shown in Figures 2a and 2b.

Figures 2a and 2b show similar views as seen in Figures 1a and 1b but using the composition of the household instead of the highest level of education. Taken together, the data available in the 4 tabs offer a richness of insight, in an accessible form, into aspects of poverty which is not commonly available to students, or indeed policy makers or journalists.


Figure 1a, 1b. Poverty rates in Ireland by education


Figure 2a, 2b. Poverty rates in Ireland by composition of household

## TASK DESIGN AND ASSESSMENT

Nicholson, Ridgway and McCusker (2009) reported that many of the statistics assessment items in high stakes assessment at GCSE level (aged 16) in the UK used data with no context, or where no use was made of the context, and in some cases using contextual reasoning would lead to an answer which was different from that published in the mark scheme. Teachers testify that the interpretation of data is the part which they find most difficult to teach, and we believe the current assessment model contributes to that problem at a time when developments in technology mean that today's students will have ubiquitous access to automated calculations and graphical representations once they leave the confines of the school education system.

It is also the part that pupils have traditionally found most difficult, especially weaker pupils who have struggled through calculations and graph drawing to get to the point where they look for the interpretation of their data.

Perverse though it may seem, it appears that working with more complex data where there are strong stories to be uncovered may free students and teachers from some of the inhibitions they experience with traditional curriculum materials. The relationships in the data come as no surprise to students – their own world experience tells them that boys and girls may behave differently, children of different ages may behave differently and that patterns of behavior may change over time. The transparent complexity of the data means that students know there is no *single right answer* in trying to describe the stories in the data, and so they appear much more willing to engage with the data and in discussion about the data.

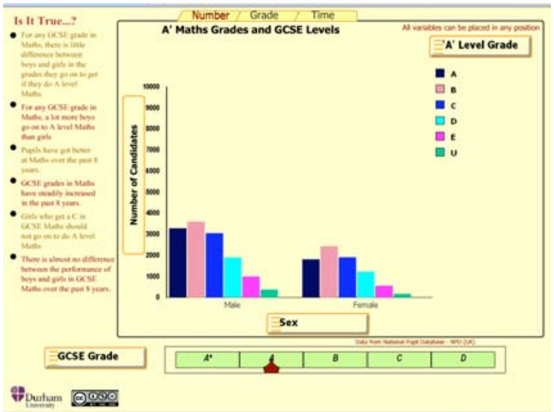
There is a scarcity of resources which offer advice on strategies for interpreting data, or on suitable language to use in describing patterns in data. Pupils need exposure to a variety of contexts that allow them to become accustomed to talking about data in situations where they already have background contextual knowledge that they can bring to bear. In our task design, the use of data is primarily to enhance understanding: the pupils do not engage in detailed calculations; and the drawing of graphs is automated while giving the user control over the way the data is presented.

In one task we created a mash-up where data from a variety of sources concerned with alcohol consumption by children aged 11-15 years were assembled as separate pages in an interactive display, alongside newspaper stories about drinking, putative associations with crime, and the effects of lessons on alcohol consumption, Nicholson, Ridgway and McCusker (2009). Newspaper accounts are rich in assertions about 'what is' that might or might not be true; and are also rich in implicit models that embody theories of causality, and solutions to complex problems. Unlike statements from statistics offices, they use a wide range of rhetorical devices, and warrants for assertions–superficial descriptions of data are often used to justify pre-existing belief systems.

In another study, we listed some provocative statements about gender performance in mathematics alongside a data interface which could be interrogated to see if the statements had any basis. The statements listed were:

- For any GCSE grade in Maths, there is little difference between boys and girls in the grades they go on to get if they do A level maths.
- For any GCSE grade in Maths, a lot more boys go on to A level Maths than girls.
- Pupils have got better at Maths over the past 8 years.
- GCSE grades in Maths have steadily increased in the past 8 years.
- Girls who get a C in GCSE should not go on to to A level Maths.
- There is almost no difference between the performance of boys and girls in GCSE Maths over the past 8 years.

Figure 3a shows the number of male and female candidates gaining different grades in A level Mathematics for students who had gained a grade A at GCSE before starting the course. The slider allows the grade profiles at A level to be viewed for other GCSE grades achieved. Figure 3b shows the same data but as proportions of the group.



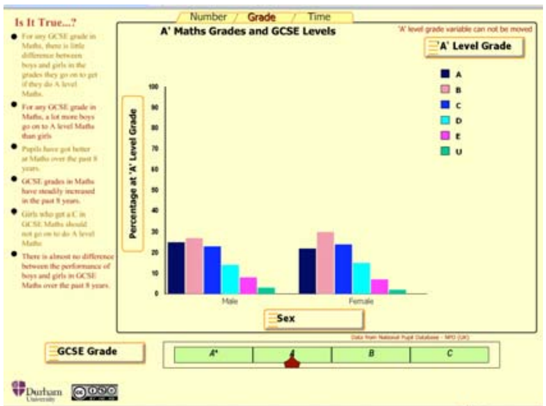




Figure 3a, 3b. A level performance in Maths by performance at GCSE

As with the data on poverty in Ireland, manipulating the position of the variables allows greater insight into the relationships within the data. Figure 4a shows the grade profiles in A level Maths for entry levels of A*, A, B and C at GCSE Maths for boys, and Figure 4b shows the same information for girls.

## DISCUSSION

Critical thinking using data is an increasingly important core life skill. Schield has looked at people's capacity for critical thinking using data presented in tables and graphs, or described in words (e.g., Schield, 2000), and at the role of confounding variables (e.g., Schield, 2006) which are important issues. The development of innovative interfaces such as Gapminder and those illustrated here allow the role of critical thinking with complex data to be developed much further.

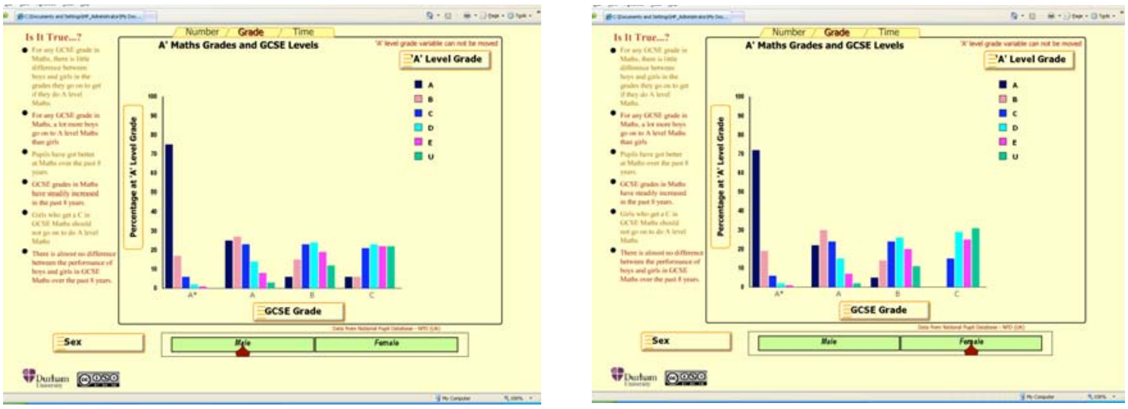



Figure 4a, 4b. Alternative representation of data on Maths performance

Our proposals for curriculum reform link two important educational and policy concerns: citizenship education and statistical literacy. H. G. Wells predicted that "statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write" (as paraphrased by Wilks, 1951). This day has long since come. There is hardly a political or social debate that does not involve the citation of statistical evidence. Newspapers and other media daily publish figures concerning economic growth, unemployment, financial markets, prediction of election results, health risks associated with certain foods or behaviours, and findings from opinion polls. To become an informed citizen, a person needs the ability to critically evaluate statistical evidence about political and social issues. Statistical literacy is vital to citizenship, and particularly students engaged in non-quantitative majors for whom advanced statistical reasoning, without resort to formal advanced statistical analysis, is becoming ever more important.

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