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Do First-Degree Science and Engineering Students have the Stats Grounding they Need?

A roundtable meeting on 29 September 2011 at the Royal Statistical Society

EXECUTIVE SUMMARY

Post-16 quantitative (including statistics) skills for all: There is a growing gap between the quantitative skills with which students leave school and what they need to study science, technology and engineering in higher education (HE). We are at a tipping point. School science is less quantitative while science degrees are becoming increasingly quantitative: more data, instrumentation and understanding complex systems demand more statistical know-how. Whilst most[1] students who study the sciences at university will have GCSE Maths (Grades A*-C), on some courses (e.g. the biosciences) only 40% of new entrants will have Maths A-Level too (meaning, of course, that 60% do not). This poses big questions about teaching on these programmes. Universities have had to reshape courses to accommodate the range of students' skills, taking time out of the core of science courses.

Improving quantitative skills teaching: Statistics education needs to be improved at all levels. Quantitative skills are integral to scientists' toolkits and yet teachers of sciences from primary to HE - who have themselves received an education with a quantitative deficit - do not all have the required skills.

Better School-HE communication: Students are too often poorly advised in their A-Level subject choices. They (and their teachers) are unaware that studying life sciences, chemistry, computing or engineering requires greater quantitative skills and understanding than those offered by GCSE maths. Maths A-Level is seen as 'hard'. Given perceived lack of flexibility around university entry requirements, it can soon become an unattractive and risky option for students who are worried that achieving a grade A or B in A-Level Maths is going to be more of a challenge than securing a high grade in another subject. They may opt to drop maths and with limited quantitative content on some science A-Level courses, may then enter university with their most recent experience of maths being a GCSE taken two years earlier. University entry requirements need to include a 'quantitative bar'. Academics need to work together to present a more realistic picture to schools of the

[1] See 'A survey of the mathematics landscape within bioscience undergraduate and postgraduate UK higher education' a June 2011 report by Dr Jenny Koenig, Science Education. Training and Communication and Lucy Cavendish College, University of Cambridge which showed that a significant minority (16%) entering bioscience courses have less than a grade C GCSE Mathematics (although they may have other non-GCSE qualifications which are accepted on some courses). *It is also worth noting that given the low GCSE maths entry requirement for Access courses and the fact that the maths component of Access to HE courses is also highly variable, it is possible for students to complete an Access course without doing much maths at all.*

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mathematical/statistics knowledge expected of students for a range of courses. This will better inform students' choice of study pathway. Work is also needed to change students and teachers' perceptions of the role of, emphasis on and need for maths on HE courses and in the world more generally

What next?: GCSE Maths does not offer an adequate quantitative skillset for students studying the sciences at university or entering the workplace. Insisting on all university entrants on science courses having A-Level Maths at a time when universities are under new financial pressure, would be a huge disincentive and – importantly - would not necessarily be appropriate for all students. What alternative approaches could be developed?

Recommended Action

- clearer signals by universities about the knowledge/skills needed on science courses
- research into the need for new relevant courses e.g. AS-Maths/Statistics for the sciences to help develop the quantitative skills needed on science courses
- embedding more quantitative methods in for example A-Level Biology, Computing and Chemistry encouraging students' sense of the relevance of quantitative skills to these subjects
- embedding more quantitative skills training in departmental training at university, with for example science-friendly statisticians working with science department colleagues to develop approaches and materials, possibly even statisticians embedded in life science departments
- increased quantitative content in postgraduate certificate of education (PGCE) training for teachers of the sciences
- (in the absence of pre-training for university teachers) more continuing professional development in statistics tailored to disciplines. A pilot group of universities might consider including a preference for existing subsidiary qualifications (AS-Statistics or Maths/specific modules in entry requirements
- more collaboration between subject bodies, universities (departments, faculties and vice-chancellors) and schools to profile and share new projects, useful materials and techniques and with exam boards, and bodies such as the QAA, to agree new approaches to entry requirements and to review and supplement where necessary, the quantitative skills paths available to students at level 3 and earlier phases of education
- building and sharing more knowledge of the need for quantitative/statistical skills in a range of work sectors so that teachers and students are more aware of the employability value of the statistics taught and learnt in school and at HE

INTRODUCTION

The meeting considered students' preparedness for STEM courses and what could be done to address the gap in their knowledge and skills at a time when there may be real scope to reshape the curriculum.

Current Quality Assurance Agency (QAA) benchmark statements on the quantitative skills required to undertake STEM degrees refer to limited statistics: in agricultural science (a need for a range of basic data and numeracy skills is cited); computing (numeracy); earth science (numeracy and communication skills); engineering (numeracy and computer literacy) and chemistry (very little mention of quantitative skills).

Around half of new undergraduates will not have taken a maths course since GCSE. This and the reduction of Maths content in science GCSE and A-Level courses are matters which have generated concern and anxiety across science institutions such as the Wellcome Trust ('Science and Maths Secondary Education for the 21st century') and maths community representative bodies such as the Advisory Committee on Maths Education (ACME). More recently, researchers on the Maths Taskforce (the 'Vorderman' report) made the case for all students to take Maths for longer - post 16 or level 3 - at a level appropriate to their needs. Employers via e.g. the CBI's 'Building for Growth' report tell us that new recruits and the existing workforce lack quantitative skills and that more maths graduates are needed in the workplace. We, in turn, are seeking stronger signals and active support from employers bodies in developing a lobby which supports quantitative skills development.

At present, we know that on many science degree courses, HE colleagues find themselves tasked with developing basic skills in mathematical modelling and having to adapt (dilute?) courses in line with the ability of students.

The Issues

As a discipline statistics helps get information from data and solve problems using data. Does the way statistics is currently taught do this?

- at primary level we see some dull and 'off-putting' teaching but we also see some which is very impressive indeed. At this level, many children like the maths side of things best but by the time they are a couple of years into secondary school, they start referring to Maths as 'dull', 'useless', 'boring' (this is a quote from Adrian Smith's 2004 report http://www.mathsinquiry.org.uk/.)

Following the Smith report, in 2006, the Qualificiations and Curriculum Authority (QCA) had commissioned the RSS Centre for Statistical Education (RSSCSE) to run a project which would look at statistics and data handling in GCSE Maths. At this time half of heads of maths in schools expressed a need for continuing professional development (CPD) in Statistics and a third of heads of science said that they needed professional development in statistics. The project generated materials using the statistical problem-solving approach, which encouraged teachers to develop their own case studies and examples.

So what attitudes are being carried forward from school to HE?

- at HE: students tend to say statistics can be boringly reduced to use of formulae; they believed the focus is on techniques and not on problem solving. The RSSCSE is undertaking research into statistics on PGCE courses. To date they have found a lot of variation between courses, and little or no time given to the pedagogy of statistics. Statistics is a non-trivial thing to teach and yet often the only time students learn anything substantial about statistics pedagogy is when they are on teaching placements - by accident and not design

- in particular if they are in a school where there is an enthusiast for the subject. A widespread, commonplace view held by PGCE students is that cross curricular stats work is hard: in practice, there is no cross curricular stats work done on PGCE courses…..and consequently it is the exception rather than the norm in schools.

What do we know about quantitative approaches in the Sciences?

Maths is more important than ever. Biology and biochemistry are increasingly quantitative sciences. There is more instrumentation alongside the massive amounts of data gathered in the life sciences from genome sequencing etc and these have introduced more quantitative detail and a more systemic view of biology.

For some, A-Level Maths could be seen as the bar or gold standard for 'properly trained' students with the necessary grounding to embark on degree courses in biology, but there is also a strong school of thought that mathematical skills should become an integral and vital part of science education.

There is widespread antipathy towards maths. In one shared scenario, three or four bioscientists had explained how they had veered from the physical sciences into life sciences because they were not good at maths at school.

If on some courses, approximately 70% of students have Maths A-Level and 30% do not this creates huge challenges for teachers in terms of the pace at which they can teach and the depth of the subject matter that can be covered.

Schools are invariably blamed for not delivering knowledgeable students to universities. However, the quality of interaction between schools and universities is not helping. The lack of qualified maths teachers in the UK means that teachers who are numerate (but do not possess a degree in maths) often have to teach maths up to Key Stage 5. (Many of these teachers took science degrees which involved limited maths and they are therefore less able to inspire students to see the connections between maths and the sciences.) In turn, university staff who, themselves, have not taken maths since GCSE, teach the quantitative elements of their course mechanically and apologetically.

We should be aiming to set students challenges which benefit them and this includes additional mathematics (including courses taught by the department) With more support students too can overcome their fear of or antipathy for the subject (there is a particular concern for students from schools without maths-qualified teachers). Maths A-Level in itself is not a perfect indicator of whether or not a student will be able to think quantitatively and apply quantitative skills on their course (the myth that there is a direct correlation between having an A-Level Maths and final degree grades, is just that – a myth!).)

At a time when there is a new financial regime in universities, it would not be wise to develop new disincentives. Above all, we should not do anything to exclude students who do not have A Level maths as this is a gap which universities can overcome.

Positive interventions recommended were to:

- generate more in-department training
- embed more maths in sciences at university (students will engage with maths when it is seen in context and connected to the subject they enjoy)
- embed maths in Science A-Levels (giving students a stronger sense of quantitative skills being integral to the sciences)
- give more thought as to why candidates for university life sciences pathways, have a restricted choice of A-Levels.

Applicants in life sciences have usually (correctly) been advised to take chemistry and biology A- Levels but then feel that they can avoid A-Level Maths and having opted to do so, do not consider other ways of building their quantitative skills. They will, almost certainly, be shocked at the quantitative demands of university courses in the biosciences.

Maths and statistics in the changing post-16 curriculum landscape

We are in a time of 'particular opportunity' thanks to three particular reports and the underlying research; the first of these was the Nuffield Foundation's 'Is the UK an outlier?' which reported in December 2010; followed by ACME's 'Mathematical Needs' research which reported in late Spring and more recently the report of the 'Maths Taskforce' (the 'Vorderman' report) in August 2011.

The Nuffield report highlighted the fact that in England, Wales and Northern Ireland far fewer students carry on with mathematics post-16 than is the case in other developed countries, placing these countries at the bottom of an international league table. All three reports recommended a large increase in post-16 provision,- the Vorderman report recommended that it should be made compulsory.

ACME's report has brought the importance of statistics teaching in school and HE centre stage.

A new piece of research 'Statistics in our Schools and Colleges' into the provision of statistics (commissioned by the RSS, funded by the Actuarial Profession) was also due to report in late 2011

All of this research is vital as there are problems with mathematic education wherever you look: as many as 25% of young people are taught Maths by non-specialists and only 15% take maths in the 6th form.

There is also a huge and systemic mismatch between supply and demand. ACME researchers estimated that of students entering HE in any year, some 330,000 would benefit from recent experience of studying some maths (including statistics) at a level beyond GCSE, but fewer than 125,000 will have done so. This creates huge problems for HE lecturers, and even larger ones for many students. Imagine teaching a chemistry class where 60% of the students have taken A-Level Maths but 40% have not.

During the course of the 'Mathematical Needs' research, when talking to employers, there were common skills areas which regularly came up:

Mathematical modelling
Use of software packages
Costings
Performance indicators
Risk
Quality Control and Statistical Process Control (SPC)

These were all areas of statistics which are both interesting and relevant and which would be preparing young people for the workplace. The above list does not look anything like the curriculum we have at present. But should it?

The ‘Statistics in our Schools and Colleges’ research had needed to classify areas of types of activity, a cycle termed the problem solving cycle had been used.

Problem Analysis – Data Collection – Data Presentation – Data Analysis

In its entirety represented an integrated experience of statistics, most like the way students would need to use statistics in their further studies and in the real world:

So knowing that this is the way statistics ought to be taught to make sense, the different aspects of this cycle were researched. – What was taught? What was not taught? And where? The findings were as follows:

Primary	Problem Analysis - Data Collection - Data Presentation (not Data Analysis)
GCSE Maths	Presentation of Data (not Problem Analysis, Data Collection or Data Analysis)
A-Level Maths	Data Analysis, some Data Presentation (not Problem Analysis or Data Collection)

Data analysis (lots of maths) is not done at school other than by students of A’ Level Maths. Students only have real experience of Problem Analysis and Data Collection at primary level.

In brief, even in A-Level Maths, students are not following the full problem solving cycle and so not having an integrated experience, most like the way students would need to use statistics in their further studies and in the real world.

Subjects which do provide a fuller and more meaningful experience of statistics are: psychology, biology and geography. (Economics almost covers the full cycle.....however, it is rare that data are collected, as economics teaching and learning tends to rely on the sourcing of secondary data).

Participants were asked to contemplate the questions raised by the picture of statistics education described. What is the current process we are putting young people through? What is it and what is it trying to achieve?

The Maths Taskforce research had been extremely well received and there appeared to be a government commitment to implementing its recommendations including - importantly - requiring all young people to do some post-16 maths. This was/is a quantum shift and gives cause for hope.

DISCUSSION

Employers contacted by ACME researchers had struggled to identify mathematical activity in their respective workplaces, sometimes replying that they did none (thereby immediately reflecting the disconnect between the maths they experienced at school and the real world application of mathematics). Although some <u>did</u> consider data handling and statistics as ‘mathematical’ and presented their SPC charts and risk assessment work as their mathematical activities.

Looking at 180 courses at 15 universities to see what could be gathered of the maths needed on those courses, ACME’S researchers had found very little useful information for young people to use to equip themselves properly for the courses they wanted to take. E.g. a course like bioscience wherein a fair amount of maths content would be expected, invariably kept reference to any mathematical content to a minimum. The crucial effect of this is that students are not choosing the right subjects.

A UK Centre for Bioscience survey had analysed the mathematical component of undergraduate and postgraduate training in the life sciences: Many students are accepted onto bioscience degrees with GCSE Maths grade B or less (poor algebra is a particular problem). It is very, very difficult to teach students in classes of students with a very wide range of backgrounds.

Most of the maths taught in HE Bioscience courses is effectively GCSE and AS-Maths but delivered in a bioscience context. Learning these skills in context improves motivation. The enthusiastic support of academic leaders is needed and there may need to be a framework of incentives for those on the ground charged with delivering the new approach.

There is a reluctance on the part of university courses to provide detailed information on the mathematical content of their courses. If they did they would need to ensure that their courses carried a 'don't be scared' warning. Above all, there needs to be better integration of maths within school and university curricula and the teaching of maths needs to be re-engineered.

Concern was raised more generally about restricting access to courses to students with a track record in maths. Schools will always push their students towards areas where students can succeed. There is always the concern that AAB students will be the preserve of Russell Group universities and that a student who is borderline BC might be discouraged from doing maths at all. There was also a 'mirror image' issue around AAB grades: a worrying story which had received a fair amount of coverage in the education press concerned a student who was thought in danger of getting a 'C' rather than a 'B' in maths and was, therefore, encouraged to drop the subject.

Exam board representatives were concerned that more students would be lost to maths. There are already many GCSE students who have the potential to access mathematics at a higher level but who would not want to risk taking A-Level Maths when they might fail to get the 'necessary' grade yet an A-level in Statistics, a more contextual subject, would be both accessible and relevant to them.

Concerns were raised that other than at primary school level, the statistics students learn seem to be an add-on. Students seem to be very much focused on doing what they need to do to achieve a pass. Many are still struggling with mean, median, mode at the time they start their degrees.

Ten years ago the norm would have been service teaching for science students by maths department colleagues and most roundtable participants looked back on this approach as a failure.. Now, at some universities, biologists teach statistics in the life sciences and they do this in the context of the subject. However, the move to bioscience teachers teaching is not without its problems as it is not underpinned by pedagogical training. One way forward would be to bring more people from industry into teaching and to encourage more support by industry colleagues (e.g. in the pharmaceutical industry) into materials development. The 'Review of Vocational Education - the Wolf Report' - which had issued in March 2011 made it very clear that there is a need for more maths in context including maths relevant to industry

Other effective models were considered too including biology friendly mathematicians working in the biology department why and this could be seen as best way forward.

Other professions are going through similar issues of understanding. How do you train people to fill the teaching roles? Technically competent people may be good at data presentation but not very good at analysis. At a professional level, people need to be able to challenge data to really understand it. Sometimes really good mathematicians cannot reach the understanding that a more reasonably competent person can.

All were agreed that Statistics is not a trivial thing to teach.

Existing ways of tackling the deficit in understanding included:

- Foundations for Computing - involving successful local 6th form maths teachers
- Engineering programmes with a foundation year of Mathematics

It was also noted that over half of all school leavers will bypass the HE sector completely. How are they equipped?

Another participant was working on a project concerned with the maths in other subjects and had started with the maths in economics and business studies (creating a link between A-level Maths and other subjects via more context-driven teaching: use of pivot tables and use of spreadsheets for modelling. The focus of the work reflected earlier comments about the importance of teaching in context. Once the context was made clear, the maths elements were easy to pull together.

The QCA-RSSCSE Review of Handling Data and Statistics in GCSE maths to everyone's attention. This project had completed in 2006 but the end report had never been formally circulated. It had been praised and its recommendations supported by the QCA, but was then not acted on. The project - see http://www.rsscse.org.uk/qca/ - had generated 8 examples of teaching different topics. Each activity contained teacher guidance, presentation materials (electronic and paper versions) and pupil worksheets. In addition the website contained links to real data which could be downloaded as random samples. These materials were designed by and for maths teachers to help embed statistical techniques within a relevant context, encouraging them to obtain their own data and to follow each investigation through to its final conclusions.

There was a lot of research in further education[2] which suggests that embedding maths in other subjects is the best way of tackling this. The issue always concerns subject-specific pedagogic skills and content knowledge, so is not as simple as asking a teacher from another discipline to teach maths. There is, for example, minimal CPD for teaching maths in engineering. The findings of the Transmaths[3] project on experiences in post-16 mathematics which improve transition to HE, suggest that modelling is not being taught well in maths degrees either.

The University of Durham's SMART Centre's resources use technology to enable learners to visualise data and to explore the patterns in data. They have data relevant to the biological sciences on sexually transmitted disease, heart risk and oxygen production in photosynthesis. By changing and controlling variables, and creating your own variables, you can intuitively explore other aspects of information offered by the data - this is possible in a spreadsheet, but the mechanics of driving the spreadsheet creates a significant barrier to use in classrooms - the key is that it does not take a lot of time to drive the SMART interface and you can very quickly see which variables are important and which are not.

The UK Centre for Bioscience - a subject centre of the Higher Education Academy – used to run a portal with resources for teachers. It was noted that it was set to close by end 2011 and participants wondered where teachers would be able to go to find resources such as the OERbital Project, Biomaths resources, a Wiki, SAS Curriculum Pathways all in one place. Noting also that when the UK Centre for Bioscience is no longer, discipline provision will move entirely to the newly centralised Higher Education Academy, a further question raised was whether universities would

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[2] In particular "You wouldn't expect a maths teacher to teach plastering" NRDC 2006www.nrdc.org.uk/publications_details.asp?ID=73

[3] the Transmaths Project has been undertaken by Manchester University's Maths Education Unit: three ESRC-funded projects investigating students' trajectories in and through maths programmes from school and college to HE. It is now promoting participation and engagement in post-compulsory maths education for STEM.

share educational resources with each other?. Those present thought that they would, as they had all found sharing generates its own returns. Pooling of resources was considered vital as good teachers would always make use of them - they help turn something abstract into something concrete. It was also thought useful for schools to have access to these resources and to build their use of software at school level.

To slightly temper this, the four types of curriculum were noted: intended curriculum, taught curriculum, learnt curriculum and assessed curriculum" and whilst the exams wag the tail and so teachers would use data visualisation tools and other materials if this were what was being assessed. Assessing problem solving skills needed to be given more thought. Controlled assessment takes time. GCSE Mathematics coursework had fallen by the wayside because of the assessment problems of 'rote coursework'.

At this point in time it would be good for students to simply learn how to problem solve and to know how, if they get it wrong, to try again. This was not easy to teach in a school system which is, in practice, all about passing examinations without gaining any skills'. At least one examination board still offered coursework in Statistics - about 1 in 100 actually did it. It seems like an easy option not to do it...but those that do realize how much they are learning. However, open-ended problems remain a challenge for teachers and students alike.

Students and teachers needed to see and understand more about the ways in which maths and the sciences change the world. There is not enough about how to apply the sciences (and statistics as a tool): where they are needed and where they can work

League tables have underpinned the assessment system. One view expressed was that the modular system has pushed us in the wrong direction. Free standing maths qualifications came about through looking at the curriculum and what support teachers needed. Despite the fact that maths students have to pull together a lot more schoolwork to study further maths, it has grown exponentially as its value has been grasped.

The ability to collect and organise data is what will be useful to young people at the end of their formal school education, on their HE courses and in the workplace (mean, mode, median are actually useful to real statisticians in the real world too).

A lot more needed to be done to promote Statistics to maths teachers (most think that it is what is in GCSE maths).

It was thought that A-Level maths was unlikely to change for some time and that there was a vacuum for those not taking A-Level maths – and thought needed to be given as to how it could be filled. E.g. maths GCSEs....or is it maths for Grade C GCSE? This was seen by participants as a huge opportunity which should not be squandered.

SCORE is the Science Community Representing Education). A SCORE -funded research project *Maths in the Sciences at A level* [4] is looking at the maths content of Physics, Biology and Chemistry A-levels. Having analysed the mathematics in science A-level papers, the opinions of teachers, HE, industry and professional bodies are now being gathered.

[4] SCORE had previously identified issues with how Mathematics in Science was assessed within GCSE Science examinations and had recommended that a set of mathematical skills should be included in the criteria for the GCSE Science specifications. New criteria were included in the 2011 specifications. SCORE then responded to partners concerned that existing A-levels did not meet the needs of students in terms of the way they assess the analytical nature of science. In July 2010, SCORE undertook to collect evidence of the type, extent and difficulty of Mathematics required in order to access the science in the current A-level specifications.

More general issues were then considered: do we need full-time specialist cross-curricular mathematicians who are permanently embedded in departments? Teaching statistics borne out of other subjects? Just as there are learning technologists who support departments, could there be statistics support of this kind? Is there a trade-off to be made? Maths for Science AS perhaps? (although it would always be preferable to see Maths embedded in other subjects.)

To move matters forward, participants were asked whether e.g. if you were the person responsible for the science course at your university - and there were one or two colleagues in this position at the meeting - it was a simple matter of putting more maths into the course? Could they and admissions officers, simply start asking for more appropriate maths skills e.g. at least a subsidiary - AS - or a relevant module - in Maths and/or Statistics?. It was agreed that unanimity was not necessarily a sine qua non….getting all universities to act in the same way would probably be too big an ask right now but if e.g. Russell Group universities were to develop new entry requirements, this would be a start. Everybody agreed that no school would be looking to provide their students with an education which would deny them access to a Russell Group university.

Participants were divided between those keen to use the leverage of the Russell Group and those who did not want to overfocus on universities which already had enough 'pulling power'. In the latter's view, this would not result in generating a new standard so much as represent a real risk factor for the universities concerned If schools are to think about teaching Maths to everybody at post 16, raising the bar for entry to Russell Group universities would not be the answer.

However, getting teachers and student to think through how to include some relevant Statistics in their A-Level choices would be an important starting point. There is a huge vacuum/gap in the offer to students for whom A-level Maths is not the right fit. The potential for a much more positive role for free standing maths qualifications needs to be considered. Also ways of making more use of the existing AS-Use of Maths and/or the AS-Statistics and/or - as a priority - undertaking work on what an AS-Maths or Stats for sciences would look like.

Other matters which need to be addressed are: how to join up the maths community and develop more collaboration - particularly for statistics - with the sciences. Employers cannot commit a representative at this sort of event and so it is not always clear how actively and proactively they can support initiatives like this but their support should also be pursued.

We should view the RSS and HEA (or bodies like this) as a mechanism for bringing people together to consider important interdisciplinary questions. There definitely needs to be more of a billboard or signpost for all the initiatives.....and to pull together resources which can be used in a range of science subjects.

Whilst this may not be a crisis, we know that the government would welcome a solution and we are convinced that the quantitative science community is well positioned to pave the way forward.