WORKSHOP REPORT

Where next for mathematics education in higher education?

A one-day meeting in honour of Professor John Blake

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Abstract

On the 10 June 2016 Professor John Blake, known to many readers of MSOR Connections for his leadership of the Maths, Stats & OR Network and his passionate support for mathematics education, passed away peacefully following a short illness. He was 69. In recognition of John's work, a number of his friends and colleagues came together to organise a one-day education meeting in his honour that comprised part of a larger event celebrating his many achievements in applied mathematics. The meeting was held in July 2017 at the University of Birmingham, a place where John spent many years of his career and established a legacy for teaching and learning from which many now benefit today. John was a man for action and the purpose of this one-day meeting was to explore the current needs and priorities of the mathematical sciences community and identify mechanisms by which we can continue to work together in a changed, and changing, higher education landscape: this article comprises a record of the thoughts and ideas of those who presented in honour of John's legacy.

Keywords: Maths, Stats & OR Network, mathematics education, teaching and learning, mathematics support.

1. Introduction

For over twenty years, and until his retirement in 2013, John Blake was Professor of Applied Mathematics at the University of Birmingham, where he held the Headship of the School of Mathematics on two occasions; he was also Dean of the Faculty of Science. In addition to his world-leading profile in mathematical research, John was amongst the first true champions of teaching and learning within higher education. He established the U.K. Mathematics Courseware Consortium (MATHWISE), a groundbreaking forerunner of later innovative uses of software in teaching and learning, and went on to lead the Computers in Teaching Initiative (CTI) Centre for Mathematics. In 2000, John became inaugural Director of the highly regarded Mathematics, Statistics & Operational Research (MSOR) Network under the auspices of the national Learning and Teaching Support Network (LTSN). As Director, he shaped a number of important initiatives through the Network (Blake, 2012) and many regard this as his greatest legacy, one that thrives to this day.

John was a passionate and committed teacher delivering a range of undergraduate courses at the University of Birmingham. In his joint foreword to the text *Transitions in Mathematics Education* (Grove et al., 2015), John commented: "*The transmission of our excitement, knowledge and* *understanding to our students is a complex challenge that demands considerable expertise, especially given the different mathematical backgrounds of our students, their diverse mathematical needs and career goals. Students will inevitably face barriers to their learning of mathematics. . .*" There is no doubt, John was fiercely committed to the enhancement of the learning and teaching of mathematics within higher education and the recognition of those involved in such endeavours.

In the now 18 years since the Maths, Stats & OR Network was established, there has been much activity to support learning and teaching enhancement, and innovation, within the mathematical sciences. John was vocal in urging the community to build upon the legacy of the Maths, Stats & OR Network: *"…may you continue to provide leadership in learning and teaching in your respective institutions in the UK, and more widely on the international stage. Do not let our legacy disappear!*" (Blake, 2012). But in recent times, higher education has undergone a period of significant change: with the recent introduction of the Teaching Excellence Framework (TEF), and changes to (i.e. the removal of) the national infrastructure to support discipline-based learning and teaching and the sharing of effective practices, there is now a need for the mathematical sciences community itself to consider the next steps and priorities for mathematics education in higher education and how the community itself may realise these. In his honour, the School of Mathematics at the University of Birmingham, with support from the Institute of Mathematics and Applications, along with John's friends and colleagues organised this one-day meeting to explore what these 'next steps' might be.

What follows are the words of those individuals who contributed to this meeting.

2. The expanding reach of the mathematical sciences and its implications for undergraduate curricula (Chris Linton)

What are university mathematics courses for? For those who have some responsibility for the education of mathematics undergraduates, I think it is valuable to consider this question periodically. Of course, there is no single answer, but nor is it the case that a university education serves only to impart knowledge to students. The answer is also time dependent.

Amongst other things, we need university courses which produce graduates with the appropriate knowledge and skills to fill the jobs that will be in demand over the coming years (a moving target that is difficult to predict) and which reflect the fact that mathematics is becoming pervasive in an ever-increasing number of areas.

There have been many reports written about mathematics over the past twenty years or so. In terms of looking forward, I would recommend the 2013 report *The Mathematical Sciences in 2025* (US National Research Council, 2013). The authors argue that the mathematical sciences enterprise in the early 21st century is qualitatively different to that of the latter part of the 20th.

One of the report's key observations is that the value of the mathematical sciences would be heightened if the number of mathematical scientists who share the following characteristics could be increased:

- They are knowledgeable across a broad range of the discipline, beyond their own area(s) of expertise;
- They communicate well with researchers in other disciplines;
- They understand the role of the mathematical sciences in the wider world of science, engineering, medicine, defence, and business; and,
- They have some experience with computation.

Of course this will only happen if they are exposed to these things. This begs the question: are our undergraduate curricula really suitable for the 21st century?

I think it is vital that students studying mathematics-related degree programmes gain a broad and up-to-date understanding of the uses to which mathematics is being put in the modern world. There are many challenges to doing this successfully. Given the rapid pace of change and the new uses that are constantly being found for mathematics, how do we ensure that lecturers are sufficiently aware to be able to impart this knowledge? How many of us could talk knowledgably about the role mathematics plays in, for example, social science networks; protein folding; climate modelling; computational biology; artificial intelligence; public health; metamaterials; compressed sensing – all areas identified in *Mathematics 2025* as ones where mathematics has a significant role to play.

As an example, consider PageRank, the algorithm used by Google to rank its search engine results. This was developed in the 1990s, bringing together ideas from linear algebra, probability theory and graph theory as well as a lot of computer science. The PageRank algorithm solves a problem which did not exist until recently. I obviously didn't learn about it as an undergraduate in the 1980s. How many of today's mathematics undergraduates learn about PageRank, something that has had a profound effect on their lives? My guess is not many, certainly not enough.

It is an example of a broader problem. Not enough effort is spent on giving mathematics undergraduates a broad and, critically, up-to-date understanding of the expansive reach of the mathematical sciences. If mathematics graduates don't know what mathematics is being used for in today's world, who is going to spread the knowledge to funders, policy makers, schoolchildren?

One of the primary causes of the massive increase in reach of the mathematical sciences over the past few decades has been the exponential increase in computing power. The pervasive nature and power of computer technology has transformed the world and we can now apply mathematics where previously there was little value.

Do we do enough to educate students as to how computers are used to apply mathematics? Do we teach students how to write mathematical software? Do we embrace phenomenology-driven enquiry, in addition to the theorem-proof paradigm? I would argue that the mathematical sciences should more thoroughly embrace computing.

Above all, mathematics graduates need to understand the link between mathematics, the power of computers, and real world problems.

3. Where next for mathematics support? (Tony Croft)

From the early 1990's the phrase "the mathematics problem" came into common usage amongst university academics. The term referred to student under-preparedness for the mathematical demands of their university courses, particularly in engineering and the physical sciences. Students were struggling with university-level mathematics and their lecturers were struggling to deal with, let alone rectify, the situation. Numerous professional bodies and learned societies reported the problem (for example LMS, 1995; Sutherland and Pozzi, 1995).

Universities were making attempts to alleviate this situation and by far the most common response was the development of mathematics support (here 'mathematics support' will be used as a short-hand for the more correct, but longer, 'mathematics and statistics support'.) The term 'mathematics support' means provision which is additional to normal lectures, tutorials and problems classes and the aim of which is to improve the performance of students, particularly but not exclusively those in danger of failing. Mathematics support can take various forms including drop-in centres, appointment-based services, pre-sessional courses and on-line resources. In recent years, the drop-in centre has become the dominant form of provision. Coventry University (1991) and Loughborough University (1996) were two of several institutions to establish large-scale mathematics support facilities. Working together, they have provided models and resources that have been adopted or adapted at many other universities throughout the UK and beyond.

It was around the year 2000 that John Blake, as Director of the LTSN MSOR Network, began his collaboration with the nascent mathematics support community. I, along with Duncan Lawson (Coventry), was a recipient of Network funding to undertake an initial survey of mathematics support provision (Lawson, Halpin and Croft, 2001; Lawson, Halpin and Croft, 2002a) and produce a guide *Good Practice in the Provision of Mathematics Support Centres*, published by the Network (Lawson, Halpin and Croft, 2002b). John's enthusiasm for supporting this community was unreserved. Under John's leadership, the Network re-published resources, for example, the very widely used *Facts & Formulae* leaflet (and others which would follow) distributing these to tens of thousands of students at UK universities. John lent his authority and gravitas to the search for funding to establish a virtual mathematics support centre, which became **math**centre in 2003 (http://www.mathcentre.ac.uk/). Today **math**centre is still a widely used resource base for both university staff and students, housing well over 1000 individual items, including 100+ hours of video tutorials designed to ease the transition into mathematics at university. Moreover, the site is also used by the academic community as a repository for a much broader collection of mathematics teaching and learning resources.

In 2002, the MSOR Network established the MathsTEAM project which produced numerous guides and case studies aimed at addressing the mathematics problem in various ways. One strand of this work was concerned with mathematics support (see http://www.sigma-network.ac.uk/ltsn-mathsteam-project-guides/. Other strands were Diagnostic Testing, and Teaching Mathematics within an Engineering/Science Context). When the **sigma** CETL (Centre for Excellence in University-wide Mathematics and Statistics Support) was established in 2005, which later became the **sigma** Network, John continued to encourage and actively sustain the mathematics support community. During the most recent period of Higher Education Funding Council for England (HEFCE) funding (2013-2016) John, notwithstanding being formally retired, chaired the Advisory Group of the Network until illness prevented him continuing in the final months of the project.

There is little doubt that John's legacy in the field of mathematics support will continue to address the serious and ongoing mathematics problem in higher education. Indeed, the problem has broadened significantly from the days when mathematics support was conceived. Newer reports continue to flag the challenges, increasingly in disciplines other than engineering and the physical sciences. The biosciences form an area where increasing quantification of the discipline is causing concern (ABPI, 2008; BBSRC, undated). Social Science is another field in which quantitative demands are increasing and students need to be better prepared for competing internationally (British Academy, 2012).

As for the future of mathematics support, the case for its continuation has been made above. But more needs to be done. Younger tutors, and especially postgraduates, need to be made fully aware of the background to the mathematics problem so that they appreciate the challenges faced by many of today's students, their diversity of expertise and interests, especially those from non-mathematical background who nevertheless need to become proficient in mathematical and statistical skills; that many are intimidated by the prospect of doing any mathematics at all at university. For these reasons and more, my view is that support centre tutors should be experienced teaching staff who want to devote time and energy to the enterprise; centres should not be solely reliant on postgraduates. Our students deserve more. There should be good career opportunities for those engaged in this valuable work. All too often, though less so nowadays, mathematics support has been a Cinderella service – something seen as 'nice to have' but not essential. Work must continue to educate university senior managers of the need for mathematics support to address the systemic issues highlighted above – to enlighten them just as John was enlightened. Finally, there is room for improvement in university mathematics teaching and if such improvement were forthcoming the need for mathematics support would surely reduce. Knowing John's commitment to the improvement of teaching through his work in the Maths, Stats & OR Network, I am sure this is something he would endorse wholeheartedly.

3. Graduate Employability – where is its place in the mathematical sciences? (Stephen Hibberd)

Graduate outcomes from University courses are emerging as a high priority area and a core feature of the Teaching Excellence Framework (TEF) (HEFCE, 2017). An aim of the TEF is to raise the profile and visibility of teaching within providers along with helping ensure graduates achieve better employability outcomes. Expectations are that the evolving TEF, currently at a developmental stage of subject level (DfE, 2017), will influence academic degree course accreditation and consequently how this might relate to employability. In this context a notable distinction must be made between 'employment' and 'employability'. The former relates to the short-term employment outcomes (see for example UNISTATS, 2017) based upon graduate employment data obtained six months after graduation. Employability on the other hand, relates to enhancing the longer-term ability and resilience of graduates to achieving their evolving career aspirations; something which is better evidenced by data showing more longer-term trends (see for example, WONKHE, 2017).

The proportion of UK school leavers going to university has now increased towards 50% and as highlighted by Waldock and Hibberd (2015), the curricula of many mathematics programmes remain designed primarily for the preparation of undergraduates for further study and research. Such degree outcomes may not sufficiently incorporate the primary aspirations of the increased and varied cohort taking mathematics degree to boost their broader career prospects. Institutions are gradually evolving from a traditional approach to higher education, with the principal learning outcomes being focussed on the acquisition of subject knowledge, skills and their application. Often additional skills are available from extra-curricular sources, such as those provided by the university careers services or other optional components. Other institutions may embrace the concept of developing student employability to support student recruitment and potentially more directly the local needs of the business and the industrial community.

Globally universities are increasingly expected to provide a broad range of outcomes in graduates to meet the expectations of students, their parents, employers and government. Correspondingly individual mathematics courses are constantly evolving to meet the local strengths and expectations of their students and their own university frameworks; in this latter regard, graduate employability is increasingly becoming an important and potentially distinguishing factor. Examples of professional competencies that could be more comprehensively developed and incorporated within a mathematics degree are provided within Table 1. Identified are four key areas of graduate competency, together with potential sample activities, that could be incorporated within a curriculum at different levels and stages; the final column identifies the personal outcomes a student might experience or attain.

Connecting academic study with skills development is a growing expectation for the transition between higher education and employment. A core emphasis within an undergraduate mathematics degree is commonly on individual student activity through lectures, problem workshops and assessment dominated by examination. This approach provides an efficient and effective mathematics subject-specific approach encouraging routine core understanding and skills. More recently, graduate expectations are increasingly focused on broader and enhanced employability skills and the subsequent expectation of significant personal career progression. Meeting such a changing emphasis encourages extending the learning outcomes for mathematics degree students.

Project activities are widely identified as a valuable skills-rich component of a mathematics degree programme but are often restricted by concerns over implementation issues such as extensive provision of individual projects, assessment and feedback. Concerns may seem intensified for group projects, however the potential for enhancement of skills and peer learning are considerable and appropriate to most career environments. At the University of Nottingham *Vocational Mathematics* modules are synoptic modules developed to enhance subject-specific knowledge and mathematical skills in areas of applied, financial or statistical modelling. Group project tasks build on core studies obtained in the earlier years of a mathematics degree in tandem with developing graduate level team tasks. Development plenary and strand workshops give exposure to skills awareness and group project activities offer essential insight into tackling unseen problems while adhering to tight deadlines. Project tasks also require relevant mathematical background research, integrating the use of mathematical and presentational software to successfully communicate quantitative ideas orally and in compact reports (posters, oral presentations and written reports) to a professional standard. Key assessment features of the modules are the development of clear grading templates, equally available for student group self-assessment to guide their project development and formal submission, and for academic staff to allow comparative assessment and provision of detailed and informative detailed feedback. For further details of this approach at the University of Nottingham, see Hibberd (2011).

	Definition	**Sample Activities**	**Desired Outcomes**
Co-ordinating with Others	Working inclusively and effectively together to collectively achieve a common goal	• Group projects • Seminars • Group presentations	• Understanding your impact and contribution within the team • Recognising the contributions of others • Commitment to achieving a common goal
Digital Capabilities	• Information, data and media literacies • Digital learning and development • Digital creation, problem solving and innovation, • Digital communication, collaboration and participation	• Projects that involve the use of appropriate presentation and statistical software • Using digital resources • Presenting and interacting over digital platforms	• Understanding effective uses of digital technologies • Confident to interact with others through digital platforms • Agility and willingness to embrace and use digital communications and technologies
Professional Communication	Ability to communicate effectively and appropriately through a variety of means, including oral presentations and communication in other languages	• Briefing report • Project dissertation • Placements • Blogs • Poster • Presentations	• An understanding of professional expectations • Ability to communicate in a clear, positive and impactful way to different audiences • How to structure and deliver relevant (technical) content • Effective delivery (e.g. use of visual aids, use of time)
Reflection	Consideration in order to develop enhanced understanding and insight in relation to professional outcomes and areas/ opportunities for further enhancement	• Post activity reflection • Self-evaluation • Action planning	• Greater self-awareness • Willingness to receive and act upon feedback • To be a reflective practitioner for self improvement

Figure 1: Professional competencies applicable to a mathematical sciences curriculum

The universal provision of substantial project activities remains an underdeveloped area of the undergraduate mathematics curriculum. Such activities have the potential of promoting individual study, research and employability skills in students and of highlighting the versatility of mathematics graduates. This is particularly relevant at a time when a number of external influences are indicating that degree specifications should embrace an extended range of subject specific and wider skills together with more feedback to students on assessments. Following the recommendation of the *Wakeham Review* (Wakeham, 2016) for professional bodies to support universities to deliver high-level STEM skills, appropriate mathematics specific modules with a strong employability element are encouraged and may now also formally contribute as part of the mathematics content towards Institute of Mathematics and its Applications (IMA) Programme Accreditation (IMA, 2017).

4. Scholarship – what's the point? (Michael Grove)

For many years the mathematical sciences community benefitted from a series of national initiatives, projects and networks each with the aim of enhancing the quality of the student learning experience in mathematics and disciplines where components of mathematics are taught. John Blake was involved in some way with all of them: through establishing, and then leading, the Maths, Stats & OR (MSOR) Network (2000-2012), something which many regard as his greatest legacy, defining the mathematical activities that would comprise part of the National HE STEM Programme (2009-2012), and his most recent Chairing of the Advisory Committee of the **sigma** Network (2012-2016).

John was not only an excellent teacher, but was committed to the creation and dissemination of effective learning and teaching practices; most significantly, he strongly believed in providing discipline-based opportunities for others to do the same. All who are involved in teaching and learning within higher education should be *scholarly*, that is collecting data and evidence for use by themselves to verify and enhance their own teaching knowledge and practice. Many extend this to *scholarship,* collecting data and evidence which is then shared with a like-minded (disciplinary or institutional) group who help verify this knowledge and use it to bring about enhancement and improvement. Others make the transition to *research* where data and evidence is collected to inform a much wider, and often public audience, and where verification may take place outside of the context of a single discipline.

There are many reasons for an individual to engage in scholarship. At the heart is the commitment to improving student learning and enhancing educational quality, but for an individual it can help them become part of a community, build an academic identity, and receive recognition for their endeavours. Being part of a community also benefits our institutions: through the collaborations that develop, and the sharing of ideas and effective practices. This will be particularly important with the Teaching Excellence Framework (TEF) being piloted in 2017/18 at a disciplinary level; if it continues to progress in this way, we will all be stronger as departments by working together.

The mathematical teaching and learning initiatives, projects and networks that existed from the late 1980s helped individuals make the transition to scholarship and become part of a community; in particular this growing appetite of those within higher education to collect data and evidence was something that I, working with Tina Overton, was able to witness first-hand through the National HE STEM Programme in particular (Grove & Overton, 2013). However since 2016, the external funding that helped sustain such communities and networks has ceased. If we wish to maintain and grow the learning and teaching community that so many of us continue to value, we need to organise ourselves and move forward without external support. Maintaining visibility is important because we need to ensure that we, as a community, are ready to capitalise on any national funding opportunities that may arise in the future. So just how do we move forward?

To begin, we need a way of communicating information effectively with all who are interested in teaching and learning in the mathematical sciences and in a way that allows newcomers to join. But there is no need to start from scratch, for example **sigma** has established a national network for those involved in mathematics and statistics support and the Institute of Mathematics and its Applications (IMA) has its Academic Representatives Network. However there are things we can readily do, for example, a JiscMail email distribution list for mathematics teaching and learning more generally is an easy and quick place to start.

We need to think about how we bring people together to share ideas and build collaborations. There is a role for our learned societies: the London Mathematical Society already offers an annual 'Education Day' and the IMA is offering support to departments to run teaching and learning workshops in 2018 through a dedicated initiative. More broadly, departments could run their own teaching and learning events and open these up to those from outside. For over 10 years the annual CETL-MSOR Conference has been a mainstay in the mathematics teaching and learning calendar; due to community support from those within England, Scotland, Wales and Ireland, it will return to its traditional September timeslot in 2018.

Publication is an important part of scholarship. MSOR Connections, the hugely popular and accessible teaching and learning journal established by the MSOR Network has restarted and is now distributed through the University of Greenwich. Both the MSOR Network and **sigma** published occasional guides on topical issues; these might be continued on an ad hoc basis as a community-led initiative and published electronically or made available through print-on-demand services, possibly by utilising support from the educational grant schemes of the learned societies to assist with design costs. At the very least, we must ensure the vast array of legacy publications remain available.

Scholarship is also about aiding and supporting the development of others, particularly as they begin their careers; this was something at which John himself excelled. The *Induction Course for New Lecturers* and the workshops for *Postgraduate Students Who Teach Mathematics and Statistics* were both important and highly valued activities of the MSOR Network. We need to find a way to re-establish and sustain them, and in doing so ensure they remain 'owned' by the community, much as **sigma** has done with its workshop for mathematics support tutors. Even further, with teaching focused routes becoming increasingly recognised across the sector we need to help those looking to extend their scholarship into educational research.

Here I have only outlined a start; there is much more that needs to be done, but there are already things upon which we can work together to ensure the legacy of John, and his work, is maintained.

5. Assessing the Value of Assessment (Jeremy Levesley)

When I first started to engage with the mathematics education community 25 or so years ago, it was no time before I was introduced to John Blake, Director of the LTSN MSOR Network. He was one of the few people who managed to span the research and teaching divide in university mathematics, and did so very successfully. I have looked up to few people in my time (and of course the number decreases with my age and general cynicism; see below) but John was one of those. When our 'parents' die, we become the grown ups, so now we are faced with the unenviable task of trying to continue his legacy.

I would like to talk about assessment, as I believe it is the tail which wags the dog of education in our society. This is not just a problem for education, but this will be the place where we experience it most keenly. TEF is a system by which the government can understand whether or not it has delivered the task of 'higher education'. REF (the Research Excellence Framework) is an assessment of whether or not 'research' has been done. The notion of assessment has been propagated (I believe) by a bureaucratic class which creates more and more opportunities for assessment, thus proliferating itself. This tendency has infected universities and their administration.

Assessment is the measurement tool by which we understand whether or not we have completed our task. We face the challenge of giving feedback to students so that they may understand whether or not they have completed their task. The main reason that students continually complain about feedback is that there is no authentic 'task'. An authentic task is one in which someone can say for themselves whether or not they completed it. For instance, I know I have cleared the high-jump bar because it does not fall off. The question to my coach is how I can learn to jump higher. Since an exam does not have any internal mark scheme, I cannot tell a student how to get 70%. Our assessment tasks need to be broken down and aligned with easy to elaborate learning outcomes. Then we can say "Yes", "No", or "Nearly", as conclusions of assessment.

We heard an interesting anecdote on the day of the workshop. A non-university colleague was talking about how they had given students some data and to come back with some sort of report on their conclusions. Some of them were fine, and others were not. To those that were not, he asked them to make them better. The university in question asked where the mark scheme was, and that there should be more detailed feedback. The external in question may not bother to work with that university again. If the students do not care enough about the task to understand what 'a good report' meant, all the feedback in the world is not going to help.

Our current education system, with its fixation on feedback, is infantilising all of the learners. They should be learning to develop their own quality compass, and that should be one of the main things that we are wishing to see. We should not be hoping that they manage to hurdle a bar that has come from my imagination, but should be being encouraged to set their own expectations, and to learn to shoot for the moon. In this world they will fail continuously, as we all do, in striving for the best. I have students who know that to get their first they can afford to get 52% in my module, and so they do. I do not blame them for this. This is a problem that we have carefully colluded in creating. Should we continue, or should we aim to address the problem?

What might a solution look like? First of all we should jettison the classification system, and develop a set of real tasks that students can complete. Make a computer programme which solves nonlinear equations. If it does not work, you do not pass. There are no 'method marks' because these are for early stage learners where the process is more important than the outcome. I do not get method marks for my papers, or for the delivery of my classes.

We need a deep set of agreed capabilities, decided at a national level, so that we have a standard. I believe that industry should help provide this (they have members of staff already who work to recruit our graduates into the workplace). The degree should have multiple opportunities for students to attempt skills, and the assessors can be anyone qualified (no need to be an academic or even a member of the university). Of course, those involved in quality assurance are going to say, *"We cannot do this, where are the standards?"* I am going to reply, prove to me that all of your paperwork has created any proper standard! The view of the world of work on the resilience of students leaving university gives the lie to this objection.

We need to make a stand against the quality assurance community. It is the child of the unproven notions of management for performance that have been eschewed by the business world to a large extent. Let us seek their input on how to run the universities. We need to push back on the creeping illness that, in the guise of Ofsted (the Office for Standards in Education, Children's Services and Skills), has stolen the spirit of our secondary teachers, and in the camouflage of TEF, will take ours too.

6. Even bigger challenges than Big Data (Gary Brown)

My work at the Office for National Statistics (ONS) is to ensure official statistics conform to the principles of the *Code of Practice for Official Statistics* (UK Statistics Authority, 2009), especially principle 4 - sound methods and assured quality. The data revolution has provided all analysts - in public and private industry - with a wealth of data previously unimaginable. Using these data for public good, successful developments such as Uber, Google Translate, and smart cars have transformed many areas of our lives - my job at the ONS is to assess whether they can also transform the statistics used by government and industry to measure the social and economic health of the nation.

We can definitely use the new data science techniques to help us innovate - data scientists analyse data to find a question (through induction) and statisticians find which data can help answer that question (deduction). Both these approaches are needed - exploration and confirmation - as they complement each other perfectly, "*having only one is madness*" (Tukey, 1980).

Big data offer a different view on the world, but to use them in the production of official statistics requires old views to be assured - value can only follow veracity, regardless of volume, variety and velocity. This requires data scientists and official statisticians working closely together - which we are doing - and ensuring the mathematics community value both disciplines, and provide the training needed for the future. We are actively involved in many courses - to ensure their relevance - and encourage the whole community to focus on these future needs, and help us target and train the workforce for the future.

The value of the academic community and mathematics teaching profession cannot be over-emphasised in the future needs of official statistics. Only by working in partnership with higher education can we fully exploit the data revolution, and ensure our statistics are fit for the 21st century.

7. Blue Skies Thinking in a Cloudy Climate – Making Sense of it All (Joe Kyle)

Had I said to John Blake that I was about to give a talk with the above title, he would have asked what it was about, probably approved (with a few caveats) and then offered the strong encouragement to find a better title – one less journalistic and cliché-ridden. And how I wish I still could rely on that blunt, kind and generous man for good, no-nonsense helpful advice; my work would be so much the better for it.

Having said that, let me turn to my reflections on the topics that exercised me in our recent meeting. The greatest piece of Blue Skies thinking I currently indulge in is a desire to turn the clock back – a not uncommon wish in people of certain age. But I don't mean simple nostalgia. Nor, as mathematicians are often heard to expound, do I think there was ever a 'golden age' in the teaching and learning of mathematics. No, I'm thinking of something far more structural. I was fortunate to have enjoyed undergraduate study at a time when education was regarded as an investment any civilised nation undertook to develop a better society (at much the same time, on the other side of the world, John was embarking on his own undergraduate journey). Now education has become a commodity to be bartered and used as a vehicle to burden young people with debt. This absurd use of 'the market' has resulted in recent graduates facing interest charges of some ten to twelve times the Bank of England base rate. I can see no justification for this and reversing this situation would be the one Blues Skies thought I would love to see come true.

7.1. Problem-solving – "oh, that's when it's in words."

These days, we hear talk of "problem-solving" so often, in so many walks of life, that there's a real danger that it will become a term devoid of real meaning, in my view. Within the realm of the mathematical sciences, though, it is the beating heart of our discipline and there are authors who take a scholarly and serious-minded approach to the topic. But all too often it is reduced to such banal strategies as "read the problem twice" (why not thrice?) and "underline the question". To be fair, I was never convinced that the greatly admired Pólya (1945) offers much substance: 'formulate a plan and carry it out' seems a little lacking in depth, to my eyes.

Given all this, I don't blame the young teacher I recently talked to who, when asked what she understood by problem-solving replied: "oh, that's when it's in words." At least she had formulated something that she could take into the classroom. My second Blue Skies ambition would be to see problem-solving discussed in more mature terms, and not as if it were some advertising slogan.

7.2. Experts and expertise

John Blake was an expert; both as an academic and as an expert witness for legal proceedings. The idea that "people [in this country or elsewhere] have had enough of experts" would be quite simply belief-beggaring.

The great C. P. Scott (1921), a towering figure as editor of the Manchester Guardian, where his tenure straddled both the nineteenth and twentieth centuries, formulated the most important dictum for all reporters: "*Comment is free, but facts are sacred*". My concern is that the cloudy climate of our times has produced an atmosphere where comment is sacred and facts are 'fake'. But my Blue Skies optimism leads me to believe that we will emerge from this dark age of debased discourse and will, as a civilisation, learn from the experience. Our students are exposed to much information and data; we have an obligation, through the mathematical sciences provision we deliver, to equip them with the skills and abilities to enable them to form their own judgements on not only what is real and 'fake', but more importantly to ask questions and challenge perceptions of what is valid and reliable. Our graduates will be a key part of the 'data science' revolution that currently seems to be taking place and such skills will be essential.

7.3. A Concrete Proposal

As we know, John Blake's supervisor at Cambridge was the precocious, and in many ways eccentric, Professor Sir James Lighthill – founder and first President of the Institute of Mathematics and its Applications (IMA). It is now nearly 40 years ago since the publication, under the aegis of the IMA with Lighthill as editor, of *Newer Uses of Mathematics* (Lighthill, 1978). The preface tells us that the purpose of the book was to introduce new applications to "*quicken the interest*" of the intended readership; the intention was to allow research and teaching to benefit from each other – principles that guided John Blake in all his endeavours. Might it not be a fitting memorial to John Blake to round up the leading applied mathematicians of the day to produce a sequel? After all, a common theme that has emerged from this meeting is how we might need to rethink learning outcomes for the mathematical sciences in light of ensuring our graduates are adequately prepared for the diverse range of careers they now enter in the 21st century.

8. Conclusion

While those of us who knew John, and regarded him as a friend, no doubt wish that this meeting might have been held under very different circumstances, we hope that we did the great man proud. Who knows what he would have made of our presentations and the subsequent discussions. He was a modest man but one who had his own views and was not afraid to share them, just like those who presented and attended in his honour. While we can only speculate as to whether John would have approved, we know that he would certainly have supported our spirit for sharing our ideas and for our commitment to enhancing the profile of teaching and learning within the mathematical sciences in higher education!

Although there are too many to list, we are enormously grateful to everyone who attended or who enabled this fitting tribute to John to take place, but particular thanks are due to Dave Smith from the

University of Birmingham for his support and willingness to include an educational event as part of a much larger celebration of John's academic work.

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