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Why Britain needs a national mathematics discovery centre

JACK ABRAMSKY

On the 3rd of January 2023, the UK Prime Minister, Rishi Sunak, first advocated that Mathematics should be a compulsory subject for all students to the age of 18. He was supported in principle by the following statement from the President of the Royal Society, Professor Sir Adrian Smith, issued on the 4th of January 2023:

> "Maths, data, statistics and numeracy are essential skills for a modern world, whether for the workplace or for playing an active role in society. If we want our economy to thrive and young people to be prepared for well paid jobs, we need a radical overhaul of our education system that will include all young people doing some level of maths to 18 years of age. The PM understands this and today's announcement is welcome.
>
> While we have some elements in place to increase maths and data skills, we need to upgrade the post-16 approach as part of wider reform at secondary and post-16. It is time for a baccalaureate style system that will give a broader education than the exceptionally narrow A-levels.
>
> Radical reform of the education system will not be easy and will take time but we need to get started now and build a cross party approach with support from teachers, students, parents and employers. This matters too much to be a political football that could be punctured by the ebb and flow of politics."

The UK government has now stipulated that Mathematics will be studied to the age of 18 by all students. The manner of implementation of such a change and the timetable for doing so still has to be worked out. The opposition has slightly different plans regarding mathematics should it win the next general election, but it too wants changes.

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The UK has a definite mathematical skills shortage as has been made clear in many reports from Government, the Royal Society, the Advisory Committee on Mathematics Education (ACME) [1, 2, 3] and other researchers.

This country produces many outstanding mathematicians, but it seems incapable of raising the general level of mathematical competency to meet the economic needs of Britain from now onwards. With more and more data sets coming on stream and regulating health, business, finance, climate, the environment, and general scientific research and development, the need for greater numbers of people with good mathematical skills increases almost exponentially. Sadly, the recent Core Mathematics qualifications in Mathematics have attracted insufficient numbers of students to make much difference to the mathematical skills shortage. [*] [†]

A major problem holding back our attainment levels is that attitudes towards mathematics in the UK are notoriously negative. Much of this is due to general mental health and mathematics anxiety [4], an emotional reaction which interferes with the ability to engage with a mathematical task for fear of not being able to perform well in mathematics given the huge stakes involved. Additionally, many people simply cannot see the point in learning mathematics at all, and this can be attributed to getting vibes from parents who were themselves not good at mathematics, and even teachers do not always make explicit the relevance and importance of mathematics. Worryingly, this will have been aggravated further by the absence of good accessible mathematics teaching during the Covid lockdowns.

So, what is the solution to achieve a more mathematically aware population of young adults going on to higher education and/or employment? The government's answer to this is compulsory study of mathematics to 18, and this includes repeating examinations of previously failed mathematics qualifications at age 16. Both these approaches are counterproductive. Coercion rarely works, and data shows that the endless repeating of exams previously failed has only a small noticeable effect (with only about 1 in 4 GCSE repeats resulting in a pass grade), and that rather it generates greater resistance to the further study of mathematics and/or numeracy. Young people need to be persuaded that it is in their own interests to continue the study of mathematics beyond GCSE. If nothing else, the financial benefits from having good mathematics qualifications are considerable. Contrariwise, not having any mathematics qualifications often results in subsistence salaries.

The success of any mathematics programme for post 16-year-olds will depend on at least four factors: (i) the thorough thought-through revision of the qualifications system as indicated by Professor Sir Adrian Smith in the

[*] Core Mathematics is an AS level equivalent qualification that helps students develop qualitative and problem-solving skills in courses that do not require AS or A Level Mathematics.

[†] Entries for Core Mathematics rose from 2931 at introduction in 2016 to 12,116 in 2021.

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earlier cited quotation; (ii) training better qualified teachers of mathematics, at all levels; (iii) sufficient government funding to train more teachers of mathematics and offer high enough salaries to ensure these teachers want to remain productive in the educational system; (iv) a serious attempt to reverse negative attitudes towards mathematics and create a genuine interest in mathematics, and also to develop a widespread public understanding of the fundamental importance of mathematics and its applications in solving the myriad of problems facing the world today. Everyone is aware of the problems of coping with climate change or controlling a pandemic; few realise the role of mathematics in arriving at solutions to these problems.

In the past, much money has been channelled into improving the quality of the teaching and learning of mathematics (the National Curriculum, the National Numeracy Strategy, National Numeracy, the National Centre for Excellence in Teaching Mathematics (NCETM), etc), and into providing additional respected qualifications such as Core Mathematics or Functional Skills Mathematics. These have had partial success, but they have not shifted negative attitudes significantly, nor have they closed the skills shortage mentioned earlier. Also, at a more basic level of numeracy, it is a shameful fact that nearly 8 million adults in the UK lack the basic numeracy skills expected of a nine-year-old.

Rishi Sunak, at a speech to the London Screen Academy on 17th April 2023, made the following observations about attitudes: "We make jokes about not being able to do maths. It's socially acceptable. We say things like 'Oh, maths, I can't do that, it's not for me – and everyone laughs. But we never make a joke about not being able to read.' So, we have to change this anti–maths mindset." [5]

How can we help change attitudes? Another approach is also needed, which as yet does not properly exist in the UK. As so often, the UK is an outlier here. Many countries have gone down the route of investing in centres where anyone, young or old, from any background, qualified or unqualified, can engage with hands-on interactive exhibits and table-top puzzles to explore the intrinsic interest, beauty, and importance of mathematics. These centres may be called Mathematics Discovery Centres, or sometimes for want of a better name they are called Mathematics Museums. The key characteristic of successful centres is that they are interactive. The Science Museum *Winton Gallery of Mathematics*. is not a mathematics discovery centre in the sense used here, being as it contains a series of glass-cased and static exhibits. Science Museums in other countries typically have a very large space with many interactive exhibits illustrating mathematical ideas.

The idea of interactive scientific discovery centres was developed by the experimental physicist Professor Frank Oppenheimer in *The Exploratorium* in San Francisco, which opened in 1969. As the name implies, intellectual exploration and hands-on experience is the motivating dynamic behind the whole concept. *The Exploratorium* contains both interactive scientific and mathematics installations and is an amazing place. Incidentally, Frank's

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brother was the theoretical physicist, Robert Oppenheimer who led the Manhattan Project to develop the atomic bomb.

Today, there are about 50 mathematics discovery centres around the world, interactive spaces devoted solely to mathematics. A number of these centres are attached to universities.

In the USA, the *National Museum of Mathematics* (*MoMath*) in New York attracts an annual footfall of 200 000 or more. It opened its doors in December 2012. It is a world leader in the field of interactive mathematics centres. New York is also home to the New York Hall of Science, which houses the famous and beautiful *Mathematica* Exhibition designed in 1967 by the architects Ray and Charles Eames. Now a new discovery centre, the Seattle *Universal Museum of Mathematics*, is being planned in conjunction with the University of Washington. One of its slogans is *Maths + You = Fun*.

In France, the famous mathematics research centre, the Institut Henri Poincaré, has recently opened the *Maison Poincaré*, and this in addition to the *Palais de la Découverte* and *La Cité des Science et de l'Industrie* means that Paris alone has three centres with interactive Mathematics Exhibitions. In Germany, *Mathematikum* [6] was launched and continues to be supported by the Justus-Liebig University of Giessen, and there are also mathematics discovery centres in many other German cities, including Dresden and Munich, and the internationally highly regarded virtual mathematics platform *IMAGINARY* in Berlin. Florence has the *Il Giardino di Archimede* (the Garden of Archimedes). In Barcelona there is the *Museu de Matemàtiques de Catalunya* (MMACA). And so, we can go round the world: India, Israel. South Korea, China, Brazil, Mexico, Dominican Republic, and Norway all have mathematics discovery centres.

The very high annual footfall at many of these centres demonstrate the enormous success of what is called informal approaches to mathematics learning and understanding. Invariably, visitors to these centres enjoy their experiences, develop positive attitudes towards mathematics, and increase their understanding of what mathematics is and why it is so important. Frequently, visitors want to revisit the centre because they have been inspired by their visit and do not feel in the least threatened by the mathematics they encounter. Mathematics discovery centres complement, but certainly do not replace, the more formal aspects of mathematics encountered in the classroom and the pressures to pass examinations. These centres provide an invaluable social dimension. By their very nature of being non-threatening they provide more ways into the subject through large and/or expensive exhibits that are simply not possible in current UK classrooms. Whether you are advantaged or disadvantaged, whether you belong to ethnic minorities, or to special-needs groups, whether you are a young child or a much older person, whether you are a parent or grandparent taking the children out for the day, a visit to a mathematics discovery centre will provide a stimulating day out.

The slogan *Maths + You = Fun* reaps its own rewards. More people will start to believe in their own mathematical capabilities and give some thought

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to the mathematical challenges that are presented to them in the discovery centre, more will understand some important mathematical concepts, more will appreciate the importance of mathematics in the modern world, and more will be persuaded to continue with some form of mathematical study beyond the formal school requirements. In other words, mathematics museums offer visitors a win-win opportunity. For many, the official mathematics classroom offers only the unpleasant experience *Maths + You = Terror*. Mathematics anxiety is widespread, and is not related to intelligence, rather it is an anxiety that affects one's performance and understanding of mathematics in certain situations. Most teachers believe their own students have positive experiences and do not suffer from mathematics anxiety, but there is plenty of evidence to suggest otherwise.

So far, Britain does not have a fully-fledged Mathematics Discovery Centre. The charity *MathsWorldUK* [7] was founded with the explicit purpose to establish the UK's first Mathematics Discovery Centre, with working title *MathsWorld*. This is still some years away and its location is still to be determined. *MathsCity* [8], a small-scale version of *MathsWorld*, was opened in the Trinity Leeds shopping mall in the centre of Leeds in October 2021 with generous financial support for the property from Trinity Leeds and the Leeds Business Development Improvement District (Leeds BID). Other donors include The Heilbron Institute, ICMS, Trinity College, Cambridge, the University of Leeds and CIVA. *MathsCity* occupies a small space of about 200 square metres and houses some forty exhibits, including table-top puzzles and activities. School parties, individual and family groups, and special needs groups are encouraged to attend, with ticket booking on-line. There have been restrictions on the total numbers that can attend at any one time because of Covid-19 and the small space available, but as of the end October 2023 *MathsCity* had a cumulative total over 27,000 visitors.

MathsCity has attracted rave reviews from visitors. Here are two:

> "Wow!! What a place *MathsCity* is, in Trinity College Leeds. We went today and spent 90 minutes doing all sorts of puzzles and learning through play. Our children were in their elements and found it mentally stimulating and whilst some bits were too hard, there was plenty to keep them entertained. There are around 30 puzzles and experiments for big and old to play on and the best thing is that if you don't have a child and/or you don't want to bring them, it is suitable for grown-ups too!"

> "There is a definite attempt to present maths as more than just arithmetic and calculation with a single correct answer. Some exhibits were puzzles with an objective, lots were something to play with or explore goal-free, which is nice to see. Here the focus – quite rightly – is on playful discovery and presenting a positive view of mathematics. I think *MathsCity* does an amazing job of its intended mission."

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MathsCity contains exhibits relating to Problem Solving, Ciphers and Coding, Boolean Logic, and Geometry. Further exhibits relating mathematics to our planet (including Climate Science) and to Design and Engineering are being commissioned right now. Another zone will be related to the mathematics of viruses and pandemics. The work taking place within *MathsCity* will feed eventually into *MathsWorld*, which has been conceived as centring around about 12 zones based on mathematical ideas and their applications. Each zone will contain at least ten exhibits so that visitors can appreciate the range and scope of modern mathematics. Currently, these twelve zones are: Number; Shape, Topology and Art; Mathematics for the Under 8s; Modelling; Medical Mathematics; Engineering Material, Design and Architecture; Problem Solving; Code Breaking; Programming, Robotics, Digital Computing, AI, Big Data; Understanding Chance and Risk; Mathematics in Space and Time, Space Exploration and Aviation; Mathematics of the Earth. Also to be considered include Sound and Music; Mathematics of Navigation; Mathematics of Sport.

These exhibits are designed to be non-threatening, challenging yet fun to interact with and engage visitors in problem solving activities and mathematical exploration. There will be a strong emphasis on the important role mathematics plays in our daily lives and in analysing the world around us. The displays and exhibits will also help develop an aesthetic appreciation of mathematics and emphasize the role mathematics has played in human cultures throughout the ages. Developing an excitement and curiosity for mathematics are key objectives for the Centre.

Apart from the interactive exhibits, there will also be some beautiful mathematical models and other static or dynamic exhibits, and a timeline for the development of mathematical ideas, putting mathematics in a historical context at different times in our history. This would follow the wall display of ‘Men of Mathematics’ (updated of course to include men and women and the contribution of different cultures to mathematics) which is an integral feature of the ‘*Mathematica*’ Exhibition in the New York Hall of Science There would also be many interesting and amusing quotations to read about maths and its practitioners, and humorous perceptions including cartoons of our subject by non-mathematicians. Story telling will be part of the narrative.

It is our goal to have an extensive landscaped outdoor area in addition to its interior space. The outdoor area would have at least two main functions: to provide a welcoming environment even before entering the building, and most importantly to provide activity areas for children and all other visitors to experience large scale mathematical structures, including sculptures which could be clambered over or through (for example a three-dimensional analogue of a Klein Bottle), a very high wave tower, swings built around the principle of Newton's Cradle or large lever constructions and so on.

The indoor space will be a floor area of at least several thousand square metres. This will encompass the exhibits space, workshop areas, a lecture

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theatre (adaptable as a cinema or a performance space), eating areas, a shop, a library, a resources area, and facilities such as toilets and cloakrooms. There will be ample wall space for posters, visual displays, and film loops. The whole centre will be a mathematics friendly milieu, where one could come to enjoy mathematics, talk mathematics over a cup of coffee, see international mathematics events on a big screen, and even research topics in the library. It should be a home to mathematics competitions such as UK Mathematics Challenges and the International Mathematics Olympiad. There will be an ongoing series of popular lectures to increase public understanding of mathematics, and there will be mathematical activities for all age groups, including young people, students, teachers, parents, and grandparents. It should also be a centre for young entrepreneurs in related areas, e.g. mathematics outreach or development of mathematics websites, and for more specialist lectures on mathematical topics, both pure and applied.

It goes without saying that the Centre will be easily accessible to large numbers of visitors, whether school parties, the local and national populations, or visitors to Britain, and it would work closely with well-known University Departments of Mathematics (and other relevant academic departments), Research Councils, Designers, local schools, councils, employers, industry and commerce, and entrepreneurs. It should generate both employment and opportunity. It should also generate profit for renewal.

Already, MathsWorldUK has a very impressive list of supporters, including professional associations, many Fellows of The Royal Society and several Fields Medallists. We also have a large team of dedicated and well-known Ambassadors who help to disseminate information about our activities. We have recently appointed a ‘Community Mathematician’, whose job it is to inspire audiences around the country with the joys of mathematics. At *MathsCity* a dedicated team of enablers, many of them students doing a PhD in mathematics, is on hand to give clues to visitors about solving the many mathematical puzzles on offer and offering help about understanding the ideas behind the exhibits. During the height of the Covid pandemic, we produced a series of forty-seven video discussions, Mathematics at *Home with MathsWorldUK*, with well-known personalities (Professor Sir David Spiegelhalter, Rob Eastaway, Matt Parker, Alex Bellos, Sarah Hart, Johnny Ball, and many others) talking about intriguing off-beat pieces of mathematics easily amenable to popularisation. We have recently had high profile visits from leading politicians at Westminster, who all seemed to have greatly enjoyed their visits to *MathsCity*, interacting with the exhibits and talking to some of the visiting students and their teachers.

MathsWorldUK is administered by our CEO, Dr Katie Chicot and a Board of Trustees chaired by Professor Margaret Brown. *MathsWorldUK* relies on grants, large-scale philanthropic donations, and donations from individuals. We need all the financial and practical help we can get to establish and develop a permanent base to house our long-term goal of a

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fully functioning interactive Mathematics Discovery Centre To this end, we are seeking interested parties, including financiers, designers and architects, Government and Local Authorities, to get in touch with our CEO or Chair [9], or to make donations directly through our website, or to leave legacies in their wills. We are also seeking collaborators - people or organizations - who can help generate ideas and designs for exhibits, or to offer to help in our public spaces. Once we are up and running, we hope to be largely self-sustaining through ticket and shop sales.

We want the *National Mathematics Discovery Centre* to belong to all sectors of the community with a stake in mathematics, whether it be Science and Engineering, Research and Development, Manufacturing and Business, Teaching, Nursing, Stewardship of the Earth, its Climate and its Resources, the Financial Sector, the Health Sciences and Medicine, Architecture and Design, Entertainment and the Arts, Space Research and wherever else mathematics plays a role.

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JACK ABRAMSKY
13 Vanbrugh Road,
London W4 1JB
e-mail: *jackabramsky@gmail.com*