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## Creating a Mathematics Discovery Centre in the UK

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# Creating a Mathematics Discovery Centre in the UK

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**Sommario:** *In questo articolo l’autrice descrive le motivazioni alla base delle attività di diffusione della matematica e del progetto che istituisce il primo museo della matematica del Regno Unito. Si presentano i progressi compiuti finora e alcuni aspetti matematici salienti.*

**Abstract:** *In this article Dr Chicot describes the motivations behind mathematics engagement activities and her project to establish the UK’s first mathematics museum. The article describes the progress made so far and some mathematical highlights.*

## 1. – Introduction

MathsWorldUK is a registered charity in the UK whose mission is to create a world-class Mathematics Discovery Centre, with working title, **MathsWorld**. We aim to advance the public understanding of mathematics so that everyone, regardless of age, background, and ability, can access and delight in the joy and power of mathematics.

The UK suffers from cultural barriers that exclude so many people from the world of mathematics, and that in turn diminishes their future prospects and opportunities. The cultural barriers can be inherited negative attitudes to maths or misconceptions about the subject. Our goal is to strengthen the culture of mathematics in the UK, to remove these unnecessary barriers.

## 2. – The case for a cultural intervention in mathematics

Mathematics is a life skill which is central to each individual’s prospects and wellbeing. You may re-

gard this as obvious, but it is not so regarded in the UK, despite urgent government reviews and actions. The UK has one of the lowest uptakes of mathematics post-16 of any developed nation [21] and this reflects our cultural attitude to mathematics, that it is boring, difficult, and pointless.

No one doubts the necessity of being literate, we need to generate the understanding that a lack of numeracy has a similarly strong impact on life chances as the abundant evidence shows.

“Good numeracy is the best protection against unemployment, low wages and poor health.” [12]

The UK’s mathematics deficit has a cost for individuals and for the public purse. KPMG, the multinational management consultants and one of the Big Four accounting organisations, published a report showing that low numeracy costs the public purse £765 million per year (when isolating the costs to those with only numeracy difficulties). If you add to this fact that numeracy and literacy difficulties usually occur together you find that the combined cost is approximately £2.4 billion.

There are further problems within industry. “There is strong demand for mathematical and quantitative skills in the labour market at all levels and consistent under-supply, reflecting the low take-up of and achievement in 16-18 mathematics

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in England relative to other developed countries.” [10]

A cultural intervention is needed to address the UK’s (particularly England’s) lack of relationship with, or culture of, maths. Looking at mathematics uptake across ethnicities in the UK shows that a person’s ethnicity is a strong factor in their relationship to maths. Those who are influenced by cultures outside the UK have a far stronger likelihood of studying maths post 16. The UK is reliant on students from non-white-British backgrounds to bolster the study rates of mathematics post 16. The same statutory provision is applied across cultures/ethnicities and this shows that changing the statutory provision of mathematics de won’t solve the problem. A person’s culture is having the strongest impact on their study choices.

“Evidence shows us that a positive attitude to maths is key to being numerate... Negative attitudes are at the root of our numeracy crisis, rather than a lack of innate talent...in order for people individually and the country as a whole to improve, and in turn benefit from raised levels of numeracy, our attitudes have to change.” [20]

### *Why is maths important in social mobility*

A person’s relationship with mathematics has broad consequences for the individual and a lack of mathematical skills and understanding can pose a serious barrier to achievement in a person’s education and career cementing a lack of social mobility. The Education Policy Institute report [22] demonstrates that the attainment gap between children eligible for free school meals and their peers is equivalent to one whole maths GCSE grade. (GCSE’s are the national standardised tests that pupils in England and Wales sit at age 16).

“Competency in numeracy is an important factor not only for the wider economy, but also for social justice and mobility. Numeracy issues are linked to reduced employment opportunities, increased health risks, higher rates of depression, increased risk of exclusion from school and increased risk of involvement in the criminal justice system.” [10]

The need for mathematical skills in the workplace is increasing and will continue to increase. Parents who do not have mathematics and numeracy skills

cannot support their children’s learning and furthermore pass on their negative attitude to maths. This in turn locks their children out of all the careers which require maths and cements a lack of social mobility.

A levels are qualifications that pupils can study post 16 in England and Wales. Typically, a pupil studies 3 or 4 A level subjects. This specialisation is one of the causes of low uptake of mathematics post 16 in the UK. “Amongst individuals whose highest qualification was an A level, pupils performing well on mathematics tests (British Cohort Study BCS70) at age 10 earn more in later life, even after accounting for holding A level qualifications. Compared to scoring in the lowest mathematics test quartile at age 10, a female in the top quartile earns a 23.9% premium, while a male achieves a 12.5% premium. Comparing individuals who have achieved the top four grades (A\*-C) in at least 5 GCSEs and who hold at least an A level or higher qualification, top quartile individuals are also more likely to be in work between ages 29 and 42 (based on a subset of individuals).” [18]

“Individuals who achieve five or more good GCSEs (including English and mathematics) as their highest qualification have a lifetime productivity gain worth around £100,000 compared to those with below level 2 or no qualifications. Attainment at 16 (GCSE) also plays a crucial role in access to higher education in England.” [18]

### *Maths for democracy and citizenship*

As we saw in the previous section mathematics is a key element in social mobility and higher earnings. If we do not take steps to address the cultural poverty of mathematics, then we are not giving equal opportunities to people from backgrounds that typically underachieve in mathematics. We are locking them out of many of the higher earning occupations.

Beyond the workplace mathematics has a role in citizenship. It is key to understanding information and therefore to our democratic and daily processes.

The whole adult population needs good numeracy to understand information, make decisions and engage in society. To participate in or follow public debate individuals need to understand and potentially challenging arguments based on quantitative evidence [4]. We should consider this ability to be a fundamental right. The lack of ability to sort cred-

ible evidence from loud voices is a threat to our democracy.

We see large portions of the population rejecting quantitative evidence. When this is applied to eg. the need to use vaccinations, it is a threat to life.

On a humbler level, even the ability to plan a journey or a holiday requires a level of numeracy and mathematics. So many of life's experiences are denied if a person is maths-phobic.

### *Maths, debt and mental health*

As with literacy, numeracy impacts on a wide range of life's issues. It is not surprising that numeracy skills allow people to manage their personal and household finances. These skills help prevent people from getting into debt, and possibly developing mental health problems as a result. [14]

National Numeracy collated research on mathematics skills and financial capability and found that numeracy was the major factor influencing people's financial capability [3], [11]. Having poor maths skills directly affects one's ability to select the most suitable loans, savings and insurance products.

Working on a person's finances alone is not enough we have to address the underlying issues with mathematics.

"A financial education program that does not specifically address numeracy has little impact on an individual's ability to make financial calculations." [5]

Poor financial capability can lead to problems with debt and mental health. People in debt are over three times more likely to have a diagnosed mental health disorder, over four times more likely to have a psychotic disorder, and almost eight times more likely to commit suicide. [14]

### *Maths, life chances and careers*

The role of the mathematical sciences is increasing in the workplace and we already have a maths skills gap. The increasing role is due, in part, to increased computing power. Other reasons are summarised in The Era of Mathematics [7] Key factors are:

- machine learning and artificial intelligence;
- optimisation for productivity;
- the need for modelling of complex phenomena and complex systems, ranging from auxin transport in

plants through to traffic flows, the weather and global warming;

- statistical analysis for evidence-based decision-making in government and industry;
- cryptography;
- the need to model, understand and predict the behaviour of novel materials and metamaterials;
- large genomics databases.

The economic areas listed above show the range of careers which require mathematical skills is varied and increasing. Whatever a person's motivation there is a mathematical career which can be found in this area.

A knock-on effect of the wide range of well-paying careers open to people with mathematics qualifications is that it is very difficult to recruit and retain specialist teachers. This has been a problem for some generations and is part of the reason for the decay of mathematics in the UK.

Beyond distinctly mathematical careers, mathematics acts as a gatekeeper to all sorts of careers. Mathematics qualifications are an entry requirement to nursing, teaching, engineering etc.

The 'Era of Mathematics' report [7] observes that mathematical sciences make an estimated contribution to the UK economy of over £200 billion annually, and a benefit to cost ratio of 588:1.

"Skilled mathematicians of a high calibre are needed and they are in short supply. To support innovation in the UK a larger workforce both within and outside academia is required." [7]

### *Maths is a gateway to STEM (Science, Technology, Engineering, and Mathematics) and higher study*

STEM careers are highly positive for the individual and the economy. A mathematics A level is usually required for higher study of all forms of engineering and physics. Chemistry requires an A in GCSE mathematics, and Biology and the other areas in STEM require GCSE mathematics.

We don't have the necessary skills in our workforce to meet the demand and furthermore the problem of insufficient STEM skills in the workforce is exacerbated by a shortage of women studying key STEM subjects post-16.

The fact that maths is a gateway to STEM subjects can mean that more women than men are ex-

cluded from these careers. Over the last 50 years girls have moved from being significantly under-represented at A levels to being ahead. In 2018 girls took 22% more A levels than boys and were over a third more likely to go to university. This is a loud confirmation of the role of culture and society in shaping people's educational choice and more importantly their achievements.

Nevertheless, girls are still less likely to take STEM A levels than boys: despite receiving 55% of A levels overall in 2018, girls received just 43% of A levels awarded in STEM subjects. Girls are just as likely as boys to take chemistry, and more likely to take biology. The most striking gaps are in physics and maths: girls accounted for 39% of 2018's maths A levels, 28% of further maths A levels, and just 22% of all physics A levels. This has a direct knock-on effect on numbers of girls eligible to study maths, physics and all forms of engineering at university and on the STEM skills shortage in the workforce.

A Nuffield Foundation report found that many undergraduate students outside of STEM subject, do not have the numeracy skills required to fully understand their course [16]. The participating degree subjects included Sociology, Geography and Criminology, and other areas highly dependent on data analysis. Only 26% of those involved had the numeracy levels of a 'C' or '4' at GCSE. The report concludes that for students like these a lack of numeracy skills may compromise future employability, especially in relation to certain graduate careers.

### *What causes this problem in the UK – The role of family and culture*

In 2007 the Department for Children, Schools and Families (DCSF) (a former government department which was roughly equivalent to Ministero dell'istruzione e del merito) commissioned a report into the parental role on learning. They found that:

“Parents have the greatest influence on the achievement of pupils through supporting their learning in the home rather than supporting activities in the school.” Amongst the many other findings of the study, it was shown that “Parental engagement is heavily linked to socio-economic status, as well as parental experience of education.” [6]

We need to work with parents to address this problem in our society. The Mathematics Discovery Centre, MathsWorld, is an intervention that takes place within families in a non-formal setting giving us a real chance to bring out another side to mathematics engagement with the whole family.

We know that ethnicity trumps socio-economic status when it comes to the study of mathematics, and this points to culture and the family environment being the key factor in determining a person's attitude to maths and it shows that the UK's has a heritage of a poor attitude to maths.

“Pakistani, Indian, Chinese and Bangladeshi pupils, as well as pupils with a mixed White and Asian background [17] and those with any other Asian background showed a preference for mathematics and science subjects compared with other ethnic groups. Clear examples of this were the uptake figures for A-level mathematics (Chinese 55%; Indian 36%; all students 21%; Caribbean 13%)”.

The study conducted by National Numeracy unequivocally shows that young children's numerical ability scores track their parents' numeracy levels [19]. There are different mechanisms through which a parent's recorded ability is transferred to their child. One key mechanism is the influence on their beliefs about their abilities as mathematics learners and the knock-on effect on motivation. It is these beliefs that we can challenge alongside bringing to life a culture of mathematics.

### *What changes attitudes to maths?*

Evidence from a significant national, longitudinal research project studying young people's science and career aspirations. ASPIRES [1], provides a strong case for support for the MathsWorld project. The research focused on building an understanding of the factors shaping young people's trajectories into, through and out of STEM education, as well as access to STEM degrees. The study, undertaken over a fourteen-year period, utilised a mixed methods investigation. It collected survey data from over 47,000 young people and conducted over 760 qualitative interviews with a longitudinal sample, which tracked 50 young people (and their parents/ carers) between the ages of 10 and 22.



FIGURA 1 – Modular arithmetic light-up puzzle.

From the overall study findings, five main recommendations, which apply directly to supporting young people’s mathematics trajectories, are made for policy makers and practitioners who want to support increased diversity and participation in mathematics specifically, and STEM more generally:

- 1) Support and value young people’s mathematics and STEM identities over time and across contexts.
- 2) Challenge ideas of maths competence as being based on ‘natural talent’.
- 3) Challenge peer sexism and create more gender-equitable cultures within maths degrees and outreach programmes.
- 4) Support more equitable experience and retention on maths degrees, particularly among students from underrepresented communities.
- 5) Facilitate greater access to key forms of social and cultural capital for young people from underrepresented communities, to support social mobility in mathematics and beyond.

The recommendations from this nationally significant research study support our charity’s goals to create a cultural intervention in mathematics. Family mathematics experiences like MathsWorld will build social capital and show young people that they can grow their mathematical skills and develop successful careers in STEM sectors.

#### *STEAM4U research evidence*

There are many ways of learning and of changing attitudes to learning as this depends on the indi-

vidual in question. Large scale research conducted by the European Steam4U project [13] has shown that non-formal learning activities can have a strong impact on the identity, self-efficacy and interests of students with low socio-economic status. The factors which affect a child’s attitude to maths are those that influence them in all STEM subjects.

This STEAM4U project (<https://steam4u.eu/>) was one of the first real random, blind, controlled trials conducted on nonformal learning. They took 1565 students from 36 schools across Madrid and Barcelona which covered a range of socio-economic statuses. The model they created identified key variables which led to an interest in studying and working in STEM and this model has a predictive capacity of 85%. This study categorically showed that outreach had an impact on STEM career choices. The impact on lower performing students was very important.

The impact on students from low socio-economic backgrounds was also especially high and important with a 9.5% increase in studying STEM in this group following a non-formal intervention.

The evidence from this research shows us that non-formal learning has a role to play in changing a family’s attitude to maths.

#### *Evidence of impact from maths centres around the world*

The experiences of mathematics discovery centres abroad (which attract annual visitor numbers > 140,000) evidence the impact of non-formal activities on the attitudes and learning processes of children and adults. These centres came together to collect the evidence which measures the impact of their work and produced the ‘mathspaces’ report. [2]

The starting point of their study was the experimental sciences learning report [8] which states:

“Data from the Programme for International Student Assessment showed that a major predictor of high achievement on the test was participation in out-of-school, free-choice learning experiences such as visits to science museums.”

This is corroborated by the Harvard Family Research Project [9] “The dominant assumption behind much current educational policy and practice is that school is the only place where and when children

learn. This assumption is wrong. Forty years of steadily accumulating research shows that out-of-school or “complementary learning” opportunities are major predictors of children’s development, learning and educational achievement. The research also indicates that economically and otherwise disadvantaged children are less likely than their more advantaged peers to have access to these opportunities. This inequity substantially undermines their learning and chances for school success.”

The mathspaces report firstly shows that collaboration with schools is beneficial when offering nonformal learning. It goes on to show the differences that a nonformal approach to learning offers. A couple of examples are:

- Timing: In the non-formal approach, each participant can use the time necessary to perform a task in relation with interest.
- Relationships: In a non-formal approach situation, the roles (authority, learner) are not previously assigned; the exchange of information is free and bi-directional.

Added to the physical element offered by a discovery centre, the makers of the mathspaces report point out that “Communication is one of the main components of competency-based learning and, of course, of collaborative dynamics. We see every day how groups of 3-5 people, who do not know each other, are formed spontaneously around an exhibit to collaborate in the solution of the challenge. Heterogeneous groups in sex, age and abilities converse, propose, verify hypothesis and try solutions.” [8] Group work is an approach not generally taken in maths lessons at school, that tend to be almost entirely based on individual learning. Having more activities that encourage this kind of working, which may better replicate how maths is used in real life to solve problems, would be welcomed by both pupils and would enhance learning. It would be the closest a formal setting could get to the benefit that is found spontaneously in informal settings.

An interactive mathematics discovery centre can provide a wholly different experience from the formal atmosphere of the classroom, which is constrained by both curriculum and qualification requirements. The informal approach of a discovery centre – where the interest and excitement are generated by a hands-on

experience between the visitor and the display – can supply dimensions of pleasure and understanding that are simply not available in classroom, or in remote learning settings.

### 3. – MathsCity Leeds

With a solid body of evidence informing our decision to work towards creating a national mathematics discovery centre, **MathsWorld**, we decided to begin our journey by establishing a smaller interactive maths space – **MathsCity**.

In October 2021 we launched MathsCity (<http://mathscity.co.uk/>) in a shopping centre in Leeds. It’s a relatively small space, 120 m<sup>2</sup>, and yet MathsCity offers informal, play-rich maths experiences and challenges, on the themes of problem solving and Geometry. We designed for a family audience, taking care that it would visually appeal to teenagers and have challenge and interest for all ages.

Our pilot discovery centre is aimed at the general public but with specific emphasis on attracting families and school pupils 11-14 years old. While it is possible to drop in for a visit, most are encouraged to book in advance. Schools can also book free workshops. Both public and school visits are chargeable. MathsCity launched in Autumn 2021 and has had over 34,000 visitors to date.

When we opened MathsCity, the majority of our exhibits were manufactured by a German mathematics museum, Mathematikum, and these



FIGURA 2 – MathsCity staff showing conic sections exhibit



FIGURA 3 – MathsCity entrance.

have proven to be first class. We visited a number of maths discovery centres and we sought exhibits from them. Favourites with visitors are the *Leonardo dome* from MMACA in Barcelona and the laser *Ring of Fire* from MoMath in New York. Alongside these exhibits we incorporated giant versions of commercial games based on logic and spatial reasoning. We collaborated with science discovery centres in the UK to make a parabola exhibit and a *pendulum waves*. Our goal was to get the right balance between challenges and demonstrations, i.e. a mix of hands-on and minds-on.

We intend to use **MathsCity** as a vehicle for the creation of **MathsWorld** which will consist of twelve zones each covering a different mathematical theme. **MathsCity** will host two zones at any one time.

In the first year of MathsCity we secured grants to work with schools and groups in the most disadvantaged areas locally. We reached over 1000 visitors with free tickets in this way.

Alongside fitting our MathsCity with our top picks for maths exhibits we created a full set of educational resources to go with each exhibit. On our site <https://www.mathsworlduk.com/exhibits/> you can see that for each exhibit there is supporting text which covers the: maths, history, people, applications and extension activities for the exhibit.

#### 4. – MathsCity Evaluation

As a new initiative there was a need to understand MathsCity's impact, and where opportunities exist, to enhance the impact. This was achieved through an

evaluation of the centre over the course of Spring 2022. Hope-Stone Research was invited to conduct this independent evaluation and what follows is based on the data and feedback collected.

The evaluation aimed to understand the impact on visitors, specifically if MathsCity has:

- Enabled visitors to enjoy maths?
- Changed visitor perception of maths?

The evaluation used a mix of quantitative and qualitative approaches to provide a comprehensive understanding of user impact.

#### *Quantitative evaluation methods*

The core element of the research was the administration of a school pupil pre and post visit survey, that aimed to measure levels of interest, understanding and confidence in maths before visiting the centre and afterwards. It also asked about visit enjoyment and suggestions for improvement. Samples achieved were:

- Pre-visit  $n = 167$
- Post-visit  $n = 113$

The pre and post visit survey data are not directly comparable as  $n = 51$  pre-visit pupils did not complete the post-visit survey. Therefore, comparisons should be seen as indicative rather than statistically accurate.

In addition to the longer surveys, shorter feedback was gathered. During April 2022 a series of short questions were asked with visitors giving answers using stickers on a whiteboard at the end of their visit. Responses:  $n = 38$ .

#### *Qualitative evaluation methods*

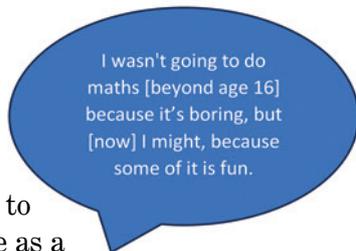
Evaluation techniques used were: Onsite 'luggage tags' comment feedback (responses:  $n = 117$ ); school visit observation; school pupil focus groups; and school teacher interview.

Where sample size allows, responses are analysed by gender and ethnicity, the latter based on those who self-identify as white or all other ethnicities (Due to small sample sizes, all those not identifying as white have been combined into the *all other ethnicities* category.) We have also calculated

a variable identifying the frequency that maths is discussed by pupils as a way of defining their personal maths engagement. In the text this is referred to as Maths Capital.

### *Impacting attitudes to maths*

- Maths did not appear to increase in preference as a subject at school post-visit, but it did appear to have increased in how much pupils felt they enjoyed it, rising from 22% who said they very much enjoy Maths pre-visit to 30% who gave the same response post-visit.
- Claimed enjoyment of Maths was higher among boys and pupils from ethnic minorities, both pre and post visit. The biggest change pre and post was for pupils from ethnic minorities, from 28% who enjoy maths very much pre visit to 45% post-visit.
- Conversely, pupil confidence in and anxiety about maths did not change significantly as a result of their visit.
- Among those planning to take Maths A level, interest in studying it at university increased significantly post-visit. However, interest in maths as part of a job did not change between pre and post-visit.



### *Learning impact of the MathsCity visit*

Pupils and families overwhelmingly said they enjoyed their visit to MathsCity. Pupils described it as “Fun, cool, exciting, enjoyable and interesting”. The experiments that captured the student’s imaginations most were the bubble and dome-making tasks and overall, the sheer number of activities on offer and the variety of their content were appreciated by visiting pupils.

Pupils enjoyed feeling challenged or having the opportunity to work on the experiments with their friends, including a competitive element.

Most pupils said they had learnt something during their visit; 23% said they had learnt a lot, a further 65% said they had learnt a little. Furthermore 31% of pupils reported that they felt more interested in maths because of their visit. In terms of a greater understanding of what mathematics is, 53% agreed

that it had made them think about maths in a new way and 66% agreed that it showed them that maths is involved in topics they’d not previously connected with maths.

Visitors appreciated the way maths was presented via problem-solving skills and perspectives, along with the hands on, activity-based approach of the sessions. Adults accompanying children seemed to enjoy the activities as much as the children, with a number doing them on their own while the children explored elsewhere.

### *Broader value of the visit*

The visit provided an opportunity for pupils to collaborate and work in teams on maths-based challenges, something that doesn’t ordinarily take place in school. The teacher believed the visit helped to reduce some of the negative feelings many pupils have towards maths by making it fun and engaging. MathsCity provides an effective intergenerational way of engaging with maths for families and other mixed groups, including younger children 5-10 and older 11-20 year olds.

Facilitators were seen as effective at enabling pupils to engage and doing so in a relaxed and friendly manner.

### *Visitor suggested improvements*

We wanted the evaluation to provide us with an opportunity to improve our work. The suggestions for improvements we received could be summed up as a request to expand MathsCity, which of course we want as well. Visitors wanted more activities, more space in the centre, more opportunities for group working and competitive elements, and more complex and challenging tasks for more capable pupils.

A useful suggestion was to create a briefing pack for schools, including a centre map to be sent to schools in advance to help pupils understand what to expect and to help them explore independently.

Family visitors additionally suggested having some seating for older accompanying adults, smaller seats for very young children and a café nearby.

### *Evaluation Conclusions and Recommendations*

Evidence suggests MathsCity has provided a stimulating and, in many cases, attitude changing opportu-





FIGURA 6 – Möbius hearts.



FIGURA 7 – Eggs decorated with marbling ink.



FIGURA 8 – Flood defenses exhibit.

run a high number of outreach activities will be familiar with this problem. We manage this in Maths-City by responding to seasonal influences. We follow the pattern of school holidays to drive most of our new activity. In Winter we run activities like hexagonal paper snowflakes, Möbius Band paper chains, fractal Christmas trees built using Sierpinski Tetrahedrons, Christmas tree decorations which are platonic solids, and the popular *Build a Giant Igloo!* (This is our Leonardo dome from MMACA.)

Before we get to Spring, we have a season of heavy rain in the UK. In this period, we have a flood defences activity. For this we are joined by researchers from the Leeds Institute for Fluid Dynamics (University of Leeds). Families explore turbulent waters with a flood demonstration using our wave tank and experiment with a choice of flood defences to observe the impact on water control. At



FIGURA 9 – Board games at MathsCity.

this time we also celebrate Valentine’s Day with interlocking Möbius hearts.

When we finally get to Spring we celebrate the International Day of Mathematics, 13th of March (3.14), also known as Pi Day . We run competitions inside MathsCity such as drawing a perfect, free-hand circle. If you want to try it there is an online game: <https://vole.wtf/perfect-circle/>. Another popular competition is the Pi-atholon (competitors have to run 314 metres, recite the first twenty digits of Pi, and eat a pie without using their hands).

During Spring we celebrate National Numeracy day in the UK, International Women in Mathematics Day (IWMD), and Easter. At Easter visitors decorate eggs with ink marbling again supported by students from the Leeds Institute for Fluid Dynamics.

Anytime of year we can run a week of board games. Laser Maze is one of our favourites. In this game players use mirrors and beam-splitters to direct lasers through mind-challenging mazes to light up the target. Another favourite is Sudoku game on the next level. Players fill a grid with skyscrapers, no two buildings of the same height can be built in the same row or column.

We frequently have input from local mathematicians on our activities. Eg. Prof Kevin Houston from the University of Leeds and Dr Peter Rowlett from Sheffield Hallam University, set up an additional table with games that featured a clever twist on the classics like Noughts and Crosses (also known as Tic Tac Toe) and a collection of physical puzzles for lo-

gical thinking. Most excitingly we linked up with one of the local *monotile* inventors, David Smith, who gifted us some original tiles.

Summer activities at MathsCity reflect what is happening in the city. One example is a celebration of *Alice in Wonderland* through a Mad Hatter’s tea party full of classic Lewis Carrol puzzles to discover and play. Lewis Carroll is well known for writing *Alice in Wonderland*, but many don’t know he was also a mathematician and a creator of a great many puzzles.

Summer is also a time for science festivals and conferences. Note that our summer photos usually feature raincoats ....

In Autumn we focus on Halloween. Visitors are taught some ‘mind-reading’ card tricks. In addition to this we have our popular origami station to make Halloween decorations to take home. As this is also when we celebrate MathsCity’s birthday, and we pull out popular maths of birthdays and cakes.

## 6. – Evolution

Part of our goal in establishing MathsCity was to create an exhibits laboratory. The plan being to then carry forwards the best exhibits into a future full size National Mathematics Discovery Centre.

### *Code Breaking*

In March 2021 we secured a grant from the Heilbronn Institute for Mathematical Research (which supports mathematics in the UK through research fellowships and activities) to support the creation of prototypes for a code breaking exhibition. Dr James



FIGURA 10 – Twitter post of MathsCity at ‘summer’ festivals.



FIGURA 11 – Mind reading trick using Hamming code.



FIGURA 12 – Pupils decode message using ancient Roman 'Scytale'.



FIGURA 14 – The interactive sand box.



FIGURA 13 – Hilary Benn, local Member of Parliament, enjoying the Cipher Wall.

Grime is MathsWorldUK's Content Manager, and he is one of the country's most prolific and experienced communicators of mathematics and of code breaking. James and a team of maths communicators and exhibit creators made outline exhibit designs on the theme of code breaking.

The prototypes have been put through their paces. Based on this product testing, we know how we want to refine the designs, and which prototypes we want to build to museum standards. Added to this we secured a grant to develop a 'wow' attractor exhibit with FAM studio <http://famstudio.co>. The resulting Cipher wall covers three levels of affine codes. Our next step is to take the most successful prototypes and build them into full museum exhibits.

### *Our Chaotic Earth*

We strengthened our collaboration with the University of Leeds, Leeds Institute for Fluid Dynamics (LIFD) and the Open University to create an exhibition will engage children and adults with exciting mathematical ideas, and also build up an appreciation of the power of mathematics in explaining natural systems and predicting changes in our chaotic Earth. The exhibits relate to the applications of mathematics in meeting the major international challenge of delivering a sustainable environment, including aspects of climate change, biodiversity, provision of energy and transport. One of the main themes of the exhibits will be stable and chaotic earth systems, with tipping points and its implications for the climate emergency.

The exhibition, titles 'Chaotic Earth' with installation date April 2024 will be crammed with exciting activities. We will use games and play to bring out topics such as: atmospheric turbulence, chaos (chaotic pendulum), avalanche demonstrations, earthquake plates and more.

Chaotic systems are looked at in depth with a number of interactivities. Playing with two chaotic double pendulums shows they will never remain synchronised. The link between this fascinating unpredictability will be related to other chaotic systems such as the Earth's weather where small changes in initial conditions can have huge effects.

Also featured is the iSandbox which is an interactive sand box where users can change variables on

the landscape such as water levels, freezing levels, the distance between contours on topographical maps and lots more. The iSandbox was installed earlier than the remaining exhibition and has quickly become the most popular exhibit.

### *Ambition for Future Content*

As we work towards establishing a permanent and large future centre, we are getting a clearer vision of what it would contain. When describing the future centre to potential visitors we say that it will show the surprising cutting-edge role of maths throughout our lives from beating disease to green technology to keeping our personal data safe.

Exhibits will be arranged in zones such as:

- **Code Breaking** – A history of the code making and code breaking arms race. Try code breaking techniques from the Roman belts to the Enigma wheels. Beat the code breaking arcade game, send a morse code message and understand how letter frequency is a code breaker's friend.
- **Surprising Shapes** – Make straight bubbles and look into the fourth dimension. Find the fastest curves to race balls down. Discover infinite 'patterns' which are never symmetric even though they are created with just one building block. Whisper into parabolic dishes and be heard 20 metres away.
- **Brain Twisters** – Discover your inner mathematician with hands on puzzles which use your faculties of logic, Tetris skills, and even word power.
- **Our Chaotic Earth** – Chaos rules the liquid systems of Earth: the mantle beneath our feet, the air above us and the oceans around us. Experiment with turbulence and with the optimal shapes for coastal defences. Understand how we can still make predictions within chaos.
- **Under 8's Area** – Soft physical play area which allows small people to start their good relationship with maths early. Building, climbing, bubbles and number fun.
- **Medical Maths** – Viruses come in weird and wonderful shapes. Explore their geometry with virtual reality. See how viruses assemble easily by shaking the virus pieces and see them falling into

shape. Fight a pandemic by modelling the spread of a disease, trying out interventions digitally, and designing testing systems. Play dice games to understand how pandemics grow and die out.

- **Space Exploration** – Experience spin like a space station and see how they are stabilised. Track a course to the solar system. Explore the atmosphere of our nearest neighbours.
- **AI** – Test whether the AIs on site can pass the 'Turing test' and convince you they are human. Can AIs write music which is tolerable? Can they read your handwriting or a doctor's? Can the AI guess where you are from based on your accent? Put the AIs to the test. Get under the skin of machine learning with experiments.
- **Awesome Numbers** Experience millions, billions and trillions. Explore infinity, and whether some infinities are larger than others. Watch how fast cells grow to make a new-born baby, and how this relates to the growth of the earth's population.

## **7. – Next steps**

Following two years of running MathsCity we sought to grow towards becoming a large national sized attraction. We submitted an application to the government *Department for Levelling Up, Housing and Communities* (a government department which has similarities to Agenzia per la Coesione Territoriale and which has responsibility for overseeing housing nationally). Our goal was to be located in the main square in the city of Bradford. This is a city which is adjacent to (and something of a poor cousin to) Leeds. We selected this city partly based on the research [9] which shows that Bradford is nationally the town/city with the "strongest case for economic support as part of the levelling-up agenda, as well as significant capacity for new economic growth". The city is undergoing development to make it a stronger cultural destination and it already houses the National Science and Media Museum.

Sadly, government funding eluded us in 2024, and so we are currently engaged in fundraising with private philanthropists to establish a much needed permanent mathematics discovery centre, MathsWorld, for the UK.

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