Mathematics Engagement Case Studies

A collection of case studies aiming to share good practice, ideas and advice for anyone working or participating in maths engagement.

Edited and compiled by Katie Steckles and Peter Rowlett, 2023

Sheffield Hallam University

Contents

Introduction

This collection of case studies aims to share good practice, ideas and advice for anyone working or participating in maths engagement.

We have spoken to a variety of maths engagement practitioners and asked them to outline what they did, why they did it that way and what they learned during the process in a case study. We hope you find them useful.

We have developed an audience segmentation model which divides people by audience group (from pre-school up to retired) and interest level (from uninterested up to expert), and tagged projects with rough topic areas. There are indices of articles by audience group (page 42), audience interest level (page 42) and topic (page 43).

This research project has been carried out by Peter Rowlett (Sheffield Hallam University), Katie Steckles (freelance maths communicator), and Greg Chamberlain (student researcher), with funding from Sheffield Hallam University as a Faculty of Science, Technology and Arts Educational Research Project.

This collection is also available via katiesteckles.co.uk/casestudies

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Published by
Sheffield Hallam University
Howard Street
Sheffield
S1 1WB

Sheffield Hallam University
Knowledge Applied

ISBN 978-1-84387-442-3

CASE STUDY 1

Alan Turing Cryptography Competition

Organisations involved: The University of Manchester

Case study written by: Charles Walkden, Andrew Hazel, Greg Chamberlain, Katie Steckles and Peter Rowlett
(This case study is written based on an interview with Charles Walkden and Andrew Hazel for this project; in the text, "we" refers to Charles and Andrew, and "I" refers to one of Charles or Andrew.)

Intended audience: Secondary school students

Maths content: Cryptography and codes, modular arithmetic, number bases, ciphers

Audience group: Lower secondary or Middle school, Upper secondary or High school

Audience interest level: Receptive, Engaged

Topics: Codes and cryptography, number

Origins of the Project

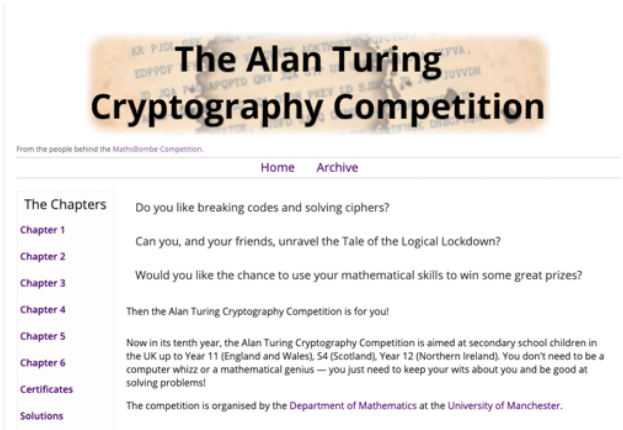
The idea for the Alan Turing Cryptography Competition came from the celebrations of Alan Turing's Centenary in 2012 - there was an organising committee which was coordinated by people at the University of Leeds, and they did a callout to ask if we wanted to do something.

Initially we thought about doing something local to the north west, partly just to strengthen some of the links between the University and the local schools and use the networks that we have for those, including our active schools-college liaison network. But we realised we could do something online so that more people had access - potentially a large number of people. Originally it was intended to focus around schools in the north west, but then it went viral and we noticed we were getting schools around the country taking part in it.

To start with, we didn't have a grand master plan, but we knew that one of the key age groups to engage was secondary schools - there's quite a lot of activities already for sixth form, and while that feels like the natural target audience for universities, actually secondary school's important too, because you want students to choose to do maths and science A-levels if you want a chance of them doing maths and science at university.

The other, more pragmatic reason is that there's the National Cipher Challenge which is targeted at sixth formers and is a lot more computer based, and we didn't want to directly compete with them. We wanted to design the early puzzles to be accessible to nearly everybody.

Practicalities



Initially, the competition ran as 6 puzzles, released every two weeks (although a few years in, this was revised to a week between the first three sets, and then 2 week gaps as they get a bit harder). The puzzles get progressively more difficult through the competition - starting really straightforward to get people interested.

The puzzles are embedded in a story - usually a mystery - told from the view of a couple of ageless children. The story often has a theme, which could be a a particular area of research which the University is particularly prominent in (such as graphene); some cultural heritage around the University (for example the John Rylands Library); or some aspect of Turing's life (for example, morphogenesis and mathematical biology).

The story structure also enables you to drop hints for some of the codes - had we not had these hints it would have been too challenging because it would not have been clear where to get started - so we used it to seed ideas.

Students sign up on the website in teams of up to 4, and they have to be registered by teachers. We also get a not-insignificant of home schooled people taking part as well, who form teams with their friends,

or sometimes siblings. A small number of students decide to take part on their own, but the team structure is there as we wanted to emphasise that mathematics is a collaborative activity.

The scoring for the competition is relative - you get a certain number of points depending on how quickly you answer it after the first person to submit the correct answer. This means if there's a really hard code, you don't have to second guess how long it's going to take people to get it. It also means that people can still feel they've achieved - we say "you've got 2 weeks to solve this" rather than saying "you have to solve this in a day".

To motivate people to solve the puzzles, we have prizes for the winners, but also a number of 'spot prizes' which are just randomly drawn from all the teams who submitted the right answer with 1 or 2 weeks of the code being released. This means people can feel it's still worth their while submitting, even if they're not the fastest.

We also have an online leaderboard where you can see which teams have solved which puzzles and how many points they've got.

There's also a forum where students can chat to each other - this often resulted, particularly for the later ones where they don't get it within seconds - a phenomenon where as soon as one team gets it (and there are people out there clicking refresh on the leaderboard) there's a sudden flurry of activity on the forum of "Oh, have you seen this team got it? That means it's doable! We've got to get cracking on this."

The questions for the competition are written by us - the hardest part is coming up with the story and deciding how the codes fit in to it. Sometimes it's quick - just generating some random symbols - and other times more work is involved, like if the question involves a video.

Examples of puzzles from the competition

Often the story comes first and then the codes - for example, when we did a challenge themed around morphogenesis and mathematical biology, it took about 10 seconds from having that idea to thinking "Oh, DNA sequencing! Do a code involving the As, Gs, Ts and Cs".

Usually, the middle part of the challenge is easiest to come up with - variations on substitution ciphers. Coming up with interesting but easy questions for the start of the challenge is quite difficult once you've used Caesar ciphers and other well-known ones.

And coming up with questions for the harder end - in a way that is interesting, isn't immediately Googleable, but isn't so hard that it's completely impenetrable - can be quite difficult. You can use a substitution cipher and obfuscate it a bit, but coming up with genuinely interesting things is usually quite hard.

We also usually try to sneak some little bits of maths in there as well - co-ordinate based codes, geometrical shapes drawn from instruction codes, or doing things with a modulus. We can then talk about it in the solutions to say "actually this is a bit of real maths". There's also the opportunity for a few in-jokes in the story - like a taxicab with the number 1729, which we explained in the solutions.

The website for the challenge was built by one of our team, and maintained by a colleague of ours - it's been tinkered with slightly, but once you've decided on the structure, there's now little maintenance required - but that was a considerable investment of time at the beginning.

As well as the online activities, we run live events at the end of each year's competition where we get the winners and up to about 200 students from across the country to visit us in Manchester for the Alan Turing Cryptography Day.

The Alan Turing Building, which houses the University of Manchester Maths department

The event runs from lunchtime up until mid afternoon - we give them lunch, then there are a number of live cryptography challenges that we give them, as a mini-competition. There's no story - just 3 fun things for them to do related to cryptography. Often these are things that wouldn't work as well online - for example, making cardboard tube Enigma machines.

The format of the mini-competition is much simpler: the first 3 teams to hand in the correct answers win prizes. Then we take them to a large lecture theatre, where someone from our sponsors SkyScanner talks to them for a few minutes, then we get someone to do an outreach-type talk - essentially to try and give a feeling of what it's like to be in a lecture at university or show them something interesting.

We also had money from the university's WP budget to fund schools in our Widening Participation programme to send students to events at the uni. For a lot of these students, particularly year 7 and year 8s this could be the first time they've been to a university and there's a lot of benefits to that, so when we ran live events alongside the competition, we get a number of WP schools taking part.

We finish the day with a Q&A if we have time, then a formal prize-giving.

Our sponsor, SkyScanner, was contacted through someone in the department, who knew that they - as many companies do - had a certain amount of money they're committed to spend supporting various charitable or other activities. We put together a case and asked if they would consider it, and they've supported us ever since.

The first Cryptography day was run using funding from the IMA and LMS, but we invited SkyScanner along to the first one. They liked it so much they offered to increase the sponsorship to cover that as well. They are mostly hands-off as a sponsor - one year they asked us if we could be a bit more proactive in embedding some of their things in the story, which we did - you can spell out quite a few things if you look at

airport codes! - I had visions of us having to do something like that every year, but since then it's basically been, you know, "we think this is good" and they've not interfered with the actual content.

As well as the actual competition itself, we've had a few things come out of the cryptography competition which wouldn't have happened without it. For example, when The Imitation Game film came out we got invited by them to set up a mini competition on cryptography based on that, which we ran in pretty much the same way as the cryptography competition. but obviously aimed at adults (and anybody else who wanted to take part). That got quite a bit of attention in the press as a way of promoting code-breaking mathematics, so that worked quite well. We also got invited for a few years to things like the Big Bang Fair and stuff like that, where one of the activities was based on code-breaking.

The pandemic has had an impact on the competition. In 2020 Cryptography Day had to be cancelled at short notice (it was due to take place shortly after the UK went into lockdown). The online nature of the competition means that it could, in principle, have run as normal even during the covid restrictions. However, we chose to run the competition in a stripped-down 'lite' version. There were no prizes, and no detailed story linked to the codes (the story became the two child protagonists sending codes to each other to crack as something to do whilst bored in lockdown – we felt that that was quite appropriate given the circumstances).

The reason for the stripped-down version was the low availability of administrative staff resource to liaise with teachers, prize-winners, etc, and constraints on our own time - given the pandemic - meaning that we wanted something that could be written quickly. There was no cryptography day in 2021. The number of students taking part in the online competition was comparable to recent pre-pandemic years. For similar reasons, we intend running a stripped-down version in 2022 as well.

Accessibility

While the event is run as a competition, this doesn't mean it's only accessible to top students who can give up loads of time to it and do really well.

The design of the competition meant that the competitive element could still function as motivation - since it's not an all-or-nothing scenario, even a team that hasn't got top place can still win prizes. The way we've set it up means that even up to the last chapter, if the team that is top cannot solve the last chapter, and the next team might have got lower scores than them, they can still win overall if they solve it quickly enough.

Even though there are prizes for winning, it's not like you're in a close competitive environment with other people nearby - in principle, it's you with your computer/phone and maybe with some friends, and you don't have anyone shouting or name-calling - I've never seen anything like that on the forums. Also, although we have set it up as a competition, it doesn't have to be run as a competition by teachers at schools - it can just be an activity, and we know of some schools who do this.

The highest level maths we include in the competition questions is number bases and modular arithmetic - it's all material that you could in principle have as a fun extension class if you went into a secondary school.

It should be possible to decode all of them by hand - obviously, it helps to have a computer, and for the later ones being able to program makes it fast - but it should still be feasible in reasonable time, once you've got the idea, to do it with pen and paper.

Almost all of the challenge is still possible for students to do if they don't all have access to the internet - the codes are almost all possible for the teacher to print and give to students in class. Occasionally we do a video-based code - e.g. morse code, but it's flashing lights embedded in a video, or something embedded in an audio file - but for accessibility reasons we have a transcript of all this ready to use if there is somebody with hearing or visual impairments.

Evaluation

Since the start of the competition we've learned a lot about how to run it and made changes over the years.

One big change was to the structure of prizes - we had too few larger value prizes in the first year. We'd assumed that we basically had to bribe people to take part while having high value prizes; we learned that that just doesn't work because it gets overly competitive and nasty, and we got caught out by that.

After that, I think from the second year, we decided that it was much better - the prizes for overall first, second and third are still more than any of the others, but they're not significant any more; it's just about spreading around the money so there are more lower level prizes for people.

We always had the spot prizes but we messed around with the distribution of them - so we've got a lot more for the early chapters now than we had, and that's partly because there are a lot more teams that complete the early chapters, by design, to share that out.

Realising that we'd got that wrong, and actually it's better for motivation purposes - it doesn't need to be very much and it's better to have the broad spread.

We haven't done any formal evaluation of the project - all the evaluation we've had is either informal from the students themselves via the forum, or after the cryptography day itself, or informally through teachers. The feedback we've had from teachers is that they do use these things, and they use past years' competitions in their lessons.

The Cryptography Day has always gone down well - the feedback we've had from teachers on that is that it's often hard to find maths things to take students to; lots of other subjects, you can go to a castle or museum, but maths is always a bit harder. They appreciate that the day is not just sitting in a lecture: there's an activity as well that's combined; and it's a similar sort of thing as well with the codes - we try and make one dead easy, one in the middle, and one actually quite challenging.

GDPR has also meant it's difficult to keep in touch with past participants and see how their participation has affected them. There are some schools that have been engaged with it from the beginning with the same teachers, so you do get an informal measure from that as to how the students are doing, and you might find out what happened to them, but we can't contact them directly.

One other big point of learning was one year when we had some help from the university with web hosting - the website fell over right at the start of the competition. When you have several hundred people all clicking refresh at 4 o'clock on Monday, essentially it's a denial of service attack and the website fell over. There was a tweak that needed to be done to limit the volume of traffic.

More information

Project website: www.maths.manchester.ac.uk/cryptography_competition

www.maths.manchester.ac.uk/cryptography_competition_the_imitation_game

CASE STUDY 2

University of Bath Cryptography Challenge

Organisations involved: University of Bath

Case study written by: Ben Sparks, Greg Chamberlain, Katie Steckles and Peter Rowlett
(This case study is written based on an interview with Ben Sparks for this project; in the text, "I" refers to Ben.)

Intended audience: Students (primary up to Uni level); Professional development for Teachers.

Maths content: Cryptography, codebreaking, ciphers, encryption, number

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College, Families (adults and children), University Students, Young Adults, Adults, Retired

Audience interest level: Receptive, Engaged, Expert

Topics: Codes and cryptography, Number

Origins of the Project

The Crypto Challenge is an event run in the school half term at the University of Bath which broadly aims promote mathematics to as wide a community as possible and to provide a half term experience for the general public, raising the profile of mathematics and the University of Bath at the same time. It began in 2015 following the success of the earlier Mega Menger project – a collaborative experience for the general public including families and university students. It is also related to the MegaPixel project from 2016.

Participants had to be on location due to the physical nature of the activities. Ideally all participants—primary school pupils through to final year university students—can find some level of mathematics appropriate to their level of experience. Cryptography is particularly well suited to this because there are a range of difficulty levels from simple ciphers to state of the art cryptographic techniques.

Practicalities

Crypto Challenge was inspired by contemporary cryptographic challenges such as those run by the University of Manchester and the University of Southampton, consisting of a series of ciphers for participants to solve. What makes our event unique is a treasure hunt aspect: in order to crack a given cipher, participants had to go to a certain location on campus.

For the event we booked a room ("Crypto HQ"), a quiet room to work in and a table outside where someone on duty would stay for the whole day.

We didn't want people to feel defeated and lose motivation early on, so for the first challenge—level 1—we chose something highly accessible and really hands-on: mirror writing; participants could hold up a mirror to reveal the secret message. Once they deciphered it, participants then had to whisper their solution to a member of the events team, which the kids absolutely loved. Unlike the usual sedentary classroom work, here maths had directly led them to do something.

The rest of level 1 consisted of backwards writing (letters reversed), a page of nonsense where the first letter of every word combined to form the secret message, and an Alphabet Cipher where the numbers in the cipher represented the letters in alphabetical order.

We felt that level 1 was accessible to everybody. With a bit of hand-holding, the event saw children as young as 6 breaking codes.

With level 2, we introduced a Caesar Cipher, Substitution Cipher, Pig Pen Cipher and the Dancing Men from Sherlock Holmes. We hoped that this would be accessible to any secondary student and perhaps diligent primary students.

Whereas level 1 and level 2 challenges gave away the key (or strongly hinted at it), level 3 introduced cryptanalysis where you actually have to crack a code (e.g. with frequency analysis) rather than just deciphering it. Ramping up the difficulty, level 3 included a Morse code audio message; participants would scan a QR code and listen using their smart phones. Level 3 also included a Vigenère Cipher and a Playfair Cipher. This required some research and was only really tackled by A-level and university students.

Participants that reached level 4 were met with 4 deliberately really hard ciphers. This involved a Playfair Cipher, autokey Vigenère Cipher and an RSA Cipher. The size of the public key for the latter was chosen very carefully so as not to be insultingly small nor unbreakably large. The final challenge was an Enigma code, which in some ways is easier to understand but does require an Enigma machine, which are notoriously hard to get a hold of; so I expected participants to find and use an online Enigma simulator.

These four levels were successful in catering for the entire range of experience. The most successful part of the event was that we had primary students alongside university mathematicians working and talking about ciphers in the same room (even if they weren't exactly the same ciphers).

When we first did this we had 3 or 4 days of this, so I was just sat on the

table for 3 or 4 days and people would drop in. The second time I ran it, a few years later, we focused on a couple of days in half term, and had a day before half term for a school to turn up as a school activity rather than a public thing.

We became aware that we didn't want to have responsibility for people running around the campus unsupervised, so we made it very clear that families who turned up would have responsibility for their own family; when schools turned up they were expected to go in groups, and we had a few student volunteers stationed around the campus. We knew exactly where the locations they were meant to go were and gave everyone a map and drew a circle within which those locations would be. It wasn't all of campus but it was far enough to give them a bit of a run around, and that physicality of it really helped. Eventually we ended up giving lat and long co-ordinates (in 2015 most people didn't know how to enter those into Google Maps so we had to demonstrate this; we ran it again in Autumn 2019 and this was not a problem because people know how to do this now).

There were hints all the way through, but they were not obvious until you spotted them. For example, the title of the second challenge was 'kcud'. After walking around the uni of Bath campus you notice it's infested with ducks! 'kcud' is duck backwards and the solution was the read the ciphertext backwards. So many of the hints were in the title of the challenge itself - the third challenge was Titled 'Definitely Useless Code Challenge' (the initials spell DUCC).

In most cases the keys were hidden in the titles. Our hint system worked well because it wasn't a hint booklet; the hints system was when we spotted this going on, or were asked for help we'd tell them to read the title and ask 'what does that mean to you'.

Challenge 6 was a Caesar cipher and said 'unducky for some' – most people decided that that meant the unlucky number 13 was involved so they tried a Caesar shift of 13 with a bit of a prompt which was the correct approach.

We did also print out a lot of copies of a 16 page A5 help booklet that described in detail some of the earlier ciphers; we deliberately didn't do this for the later ciphers because a help booklet explaining RSA is a textbook basically! It also went through the vocab like steganography, cryptography, cipher, code, etc. and this was helpful in our conversations with people. This was not so much a hint thing but it was the 'teachy' bit which is really hard to teach successfully: you could do a lecture on the vocab of cryptography but I'm not sure people would have turned up with much excitement to that – or listened for that matter. This was a way of drip feeding that information when they needed it. So the help booklet had a few hints in there as well and discussed how to look for hidden messages and things in there. So occasionally we directed them to that.

Visitors were aware that there were multiple levels to the challenge. The latest iteration of this was last year; when they turned up to Crypto HQ where me and Tamsin or one of the student volunteers was on duty, we had four locked boxes really visible with 4 digit combo padlocks, each for a different level.

If you solved all 4 challenges of level 1, you had the 4 digits to open the padlock for the level 1 box. On arrival they could see there were 4 levels and they could pick up a pack for level 1, 2, 3 or 4. Judging by their enthusiasm and confidence we could give them a pack we thought was appropriate.

Having solved level 1, which took about 10 minutes whatever their age, they would immediately come and ask for the level 2 pack. They could always come and chat to us at the desk and ask what's in the next level.

So there was a strong motivation not only in the challenges directing them physically somewhere, when they'd solved 4 of them for the whole level they could come to the desk and try to unlock the box which contained a pile of chocolate coins or something similar in box 1. I think in box 2 there was more chocolate and some gluten free options.

Box 4 we hyped up as being for the pros and it had large bars of chocolate but also three £10 notes just loose in the box; anyone who unlocked box 4 was allowed to take one.

The boxes provided a nice focus for getting a whole level done before moving on to something else. There's something really tangibly exciting about the box being right here, not even hidden, but you couldn't get into it. We didn't let people just brute force the padlocks trying all the combinations because that's really embarrassing if you're just standing right there.

This way even those students who turned up and only solved level 1 and opened the box could leave having had a complete experience or move onto level 2 if they wanted.

We did have a few university students who solved all four levels; they collected their money and were very chuffed with it. They ended up helping us man the volunteer desk. One was running a Python script to bash through the Vigenère cipher at the end. They ended up being expert helpers and we'd ask them to talk to others because they knew all about these codes and everything.

We sent out a call to all undergraduates on the maths and CS courses to volunteer. We had a short meeting the week before where I talked them through the ciphers; a lot of them wanted to go away and solve them on their own though and that was fine. In practice, few finished all that in advance.

We had a little rota of when they'd turned up and their job was either to sit at Crypto HQ and welcome people and point out how the levels worked, or to float around the work room and make sure there were pens and pencils and a few Caesar wheels and things and just chat to people. The volunteers did really well with the latter, and that's the really urgently important part of the day – if there's just a vacuum and people don't know what they're doing and no one can step in for help then I think it's a lot harder to keep the atmosphere. As it happened, in that work room it was a really lovely atmosphere.

We had a few very very low level activities for those who couldn't engage with level 1 – maybe they can't read, particularly if they turned up as a family with an older student; we had a few things written around the room in UV pens, and we provided UV pen lights so they could go and find a shape hidden in a room. There were a few primary and below challenges in the work room – things like, not a dot-to-dot, but something where you colouring in the right shapes and a picture appears. It's the same sort of feeling as decrypting something. The first time we ran this in 2015 we didn't have this and so those primary and below students became bored. These simple token activities kept them busy and entertained.

The younger students were definitely exposed to higher levels of maths than they might see at school. Everyone who turned up either could have done or did level 1, but when young students finished level 1 they would move onto level 2 - which they spent ages on, because doing a substitution cipher by hand is time consuming.

Not all of the tasks require a high level of attention to detail - with the earlier ciphers (substitution and Caesar) you can get away with making an error or two, which was useful. The younger students didn't always deal with the frustration and patience very well and that was where

having helpers around was absolutely necessary when they got stuck.

The four levels really helped to manage calibrating the difficulty of the tasks, and avoiding frustration. It didn't matter which level they ended up finishing - if people finished the level (and I think everyone finished level 1 if they wanted to) they got a successful feeling.

Visiting campus may also encourage people to consider studying maths at university - at least one student wrote to me saying they are now studying on campus at Bath and said "It was your crypto thing back in 2015 that made me choose to come and do maths."

Accessibility

We were aware not everyone would have a mobile device with them, so we had a couple of laptops at Crypto HQ with Google Maps always open so people could use that. They were also available for people to read about ciphers on Wikipedia. In practice, most used their own devices - if they came as a group, someone had a device.

For school visits we had to make sure to have paper copies available because students did not necessarily have phones. This was surprisingly good because they ended up having to talk about co-ordinates and what latitude and longitude meant.

The area the challenge took place in didn't all have level access - because of the way the campus worked - but there were lifts, so we did have a few people with accessibility issues who couldn't use stairs and we managed to get them around. That was the hardest thing to deal with: to make sure all the locations were within eyesight and not too predictable, you have to send them further afield. There were a few staircases. The Uni of Bath campus has a parade, and there is a lift to get on, but it was broken on the first day of our challenge – that was an accessibility problem we did not foresee. We had a phone call from someone who couldn't get on campus. But this is more a university issue rather than an issue with our design.

Part of our discussion was about whether it would be possible to create a version of it that is possible to do just online or without travelling around. We made all the challenges available online and you could go and solve them without leaving your home if you wanted to. The problem with that was a few people did that and wrote in to say "I've solved them all; can I come in?" – it wasn't enough for them in motivation terms just to solve them at home, they wanted to get the physicality bit.

The best feedback we got verbally was not really solving the puzzles, though that is necessary - it was the excitement of "there's something hidden there and only I know about it" and you had to implement your solutions physically.

Challenges and Evaluation

Evaluation of the project wasn't extensive - we didn't ask participants for opinions or qualitative feedback. Mainly, we collected participants' names and context, so we had an evaluation of reach. If they were from a local school we asked them to write down their school, but that was the only geographical data we had.

The very first time we ran it we asked participants for their email address. I had a score sheet keeping track of who solved which challenges all the way through to the end. By the end of the week I looked at the who solved the most challenges and quickest and I sent them a book. That was part of the advertising at the beginning - a prize for the team that does best.

Developing the challenge has been an ongoing process. We adapted the challenges each time, especially the earlier ones depending on location. We learned that the opening challenges should be more accessible than we had first thought - even the older students enjoyed the mirror writing and stuff.

We learned that the first challenges shouldn't be too far away so people weren't being sent across campus for the first challenge. One person misread it and ended up spending an hour getting lost on the first challenge.

Those are the obvious things that you iterate when you do a project like this.

The excitement of the physical element - some paper mathematics to solve followed by a physical result of that (somewhere to go, something to find, something to do) was a really lovely combination.

There are problems perhaps with the competitive element. For the 2019 run we made it more about opening the box than beating other participants (you vs. the box instead of you vs. everyone else). I think that was better overall – teams could be competitive if they wanted to bit it wasn't the focal point. It was just 'can you beat the system?' and that is something that we'd do again.

We'd spent a long time writing the ciphers specific to the uni of Bath campus; if someone demolishes the building you have to rewrite the ciphers. But the nice thing is that once it's all designed you can run it again whenever you like on campus.

Talking to car parking control at the uni was important. If we had just organised a day for the public to turn up, we have to check that they haven't organised a major conference and the car parks are gonna be full. Turns out at the uni of Bath, they're always full! But hey, talking to them meant that we knew people at least had permission to park there.

Things like room booking: do that as early as possible! Because university scheduling can be a bit of an nightmare. For example, we booked rooms and they scheduled exams in the rooms around us! And then they told us we couldn't make any noise whatsoever in this area. We had to have the discussion and they eventually moved the exams.

More information

Crypto Challenge Website: sites.google.com/site/cryptomathsbath

2019 Event Website:
sites.google.com/view/crypto-maths-challenge-2019

CASE STUDY 3

Manchester MegaPixel Project

Organisations involved: Matt Parker, Katie Steckles, Stand-up Maths Limited/Think Maths, Manchester Science Festival, Joshua Phillips Award, University of Salford

Case study written by: Katie Steckles

Intended audience: Visitors to the Science and Industry Museum during Manchester Science Festival – families (including children down to age 8) and individuals/groups of adults

Maths content: RGB displays and storing images as numbers; proportion and percentages

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College, Families (adults and children), University Students, Young Adults, Adults, Retired

Audience interest level: Engaged, Receptive, Expert

Topics: Hands-on, computer science, number

Matt Parker and Katie Steckles

The MegaPixel project took place in 2016 as part of Manchester Science Festival, as a joint project with Think Maths. Katie Steckles was the lead and organiser on the project, and it was funded by the Joshua Phillips Award and the University of Salford, and supported by Edding.

Visitors to the Science and Industry Museum during Manchester Science Festival – families (including children down to age 8) and individuals/groups of adults – were invited to take part in an activity and learn about RGB displays and storing images as numbers, as well as proportion and percentages.

Origins of the Project

Katie was awarded the 2016 Joshua Phillips Award for Innovation in Science Engagement, which came with a budget to deliver an activity as part of Manchester Science Festival. She had helped deliver large-scale mass-participation hands-on activities as part of the Festival previously, and working with Matt Parker and the team at Think Maths developed the idea of creating a giant pixel image to illustrate the way display screens store colours as numbers.

As well as being a way to communicate the maths and science behind RGB displays, the project would involve every visitor to the museum being given the chance to participate in creating an image on display at the museum. This would allow people to feel part of something, while also watching a large, exciting and visual display take shape.

Practicalities

The image took up all four floors of a window which ran the full height of the building, and was made from 'pixels' of acetate about 10cm square, each of which was coloured using red, green, blue and black permanent markers in different proportions depending on the colour of the pixel. MegaPixel had a stall and tables in the front entrance of the museum where people could come and hear about what they were doing, take a pixel or a few to colour in, and return them to go into the finished image. Anyone who did this got a sticker reading 'I made a pixel for the MegaPixel!'.

A 'hack day' was organised ahead of the event to develop the hardware and software, at which we implemented a pixel scanner, and a system that generated stickers to go on each pixel for sorting. Working with with a local FabLab hackspace, a callout was made for volunteers on Twitter and through the Science Festival. This attracted some local makers, coders and mathematicians, who also helped deliver the activities at the festival. The volunteers were all given a t-shirt with the

project logo, and refreshments provided during the event, and received briefings and training on how to interact with the public.

A website was built for the project, and Katie promoted MegaPixel on Twitter and with a YouTube video on Matt Parker's channel ahead of the project, to encourage people to join in/visit. Visitors to the museum for other Science Festival events could participate as they entered the museum, on their way to other events happening onsite. The event was also advertised through the Science Festival's website and printed programme, distributed to communities around Manchester.

To attach the pixels to the window, a high access platform and safety equipment were hired. This required some liaison with the museum on PPE and procedures. The pixel sections were sellotaped to the window (cleaning the tape marks off the window after the project was completed also had to be costed in). Edding donated all the pens needed, and were an official sponsor of the project – having approached several other major permanent marker companies, with the offer of publicity (sending out pens to schools and using them on the day) and sponsor credit in return for pens, Edding responded. The project budget covered acetates, tape, printing, stickers, equipment and t-shirts/refreshments for the team.

As well as the pixel colouring activity, the stall also had some other worksheets exploring RGB and Hex colours, and a microscope to allow people to examine phone and tablet screens closely and see the pixels are made up of red, green and blue segments. There were also red, green and blue light torches to demonstrate colour mixing, and a photo booth which converted photos taken into pixelated versions, which were printed on the spot for participants to take away (also developed by the Hackday team).

Some sections of pixels, along with activities, coloured gels for torches, and marker pens, were sent out in packs to schools and other organisations who coloured them ahead of time and posted them back. These were incorporated into the finished picture. During the festival, the team completed all but the top few rows of the image, which could be seen from in the yard outside the museum.

Pixel colouring

Accessibility

The colouring and activities were completed on tables in the main foyer of the museum, which was wheelchair accessible, and explanations and support were available from our team. It was possible to participate with a variety of levels of understanding – simply colouring in the right number of squares, or knowing how this relates to technology. Written explanations were available on the worksheets as well as a spoken explanation. Participating involved speaking to one of our team to take and return pixels and receive instructions, but at any given time multiple team members were available, and tried to be approachable and friendly. The activity was not suitable for participants with visual impairment, as the pixels were small and needed to be seen in order to colour them in.

The project also provided materials online for people to generate and complete their own mini-MegaPixel images at home, and a satellite event at the University of Bath made use of this to complete a smaller image of Leonhard Euler, which they hung in a window in their maths department.

More information

Project website: megapixel.katiesteckles.co.uk

Twitter account: twitter.com/mcrmegapixel

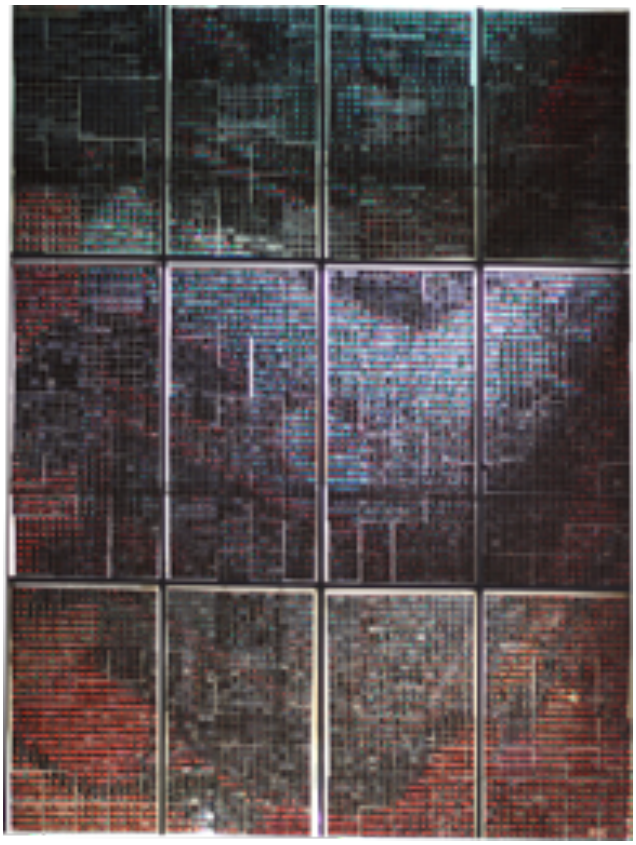


Photo of finished MegaPixel image

CASE STUDY 4

MathsWorldUK - Hands-on maths at Gipton Together Summer Camp

Organisations involved: MathsWorldUK

Case study written by: Katie Chicot

Intended audience: Inner city children attending Gipton Together Summer Camp, age range 4 – 16 years.

Maths content: Measuring, Construction, Shape, Code breaking, Problem Solving

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school

Audience interest level: Uninterested, Receptive, Engaged

Topics: Measuring, Hands-on, Shape, Codes and cryptography, Problem Solving

The Henry Barran Community Centre, Gipton. Photograph from Google Streetview.

Origins of the Project

The mission of MathsWorldUK is to improve the culture of mathematics in the UK. We want to build resilience in our audiences and show that there are many faces to maths which can be fun, can be challenging and can be surprising.

MathsWorldUK wanted to try its activities in a range of settings and audiences. We particularly wanted to test our material on an audience which is traditionally harder to reach. The 2019 Summer Camp gave us the chance to work with disadvantaged children of all ages in a setting familiar to them.

The Summer Camp has previously offered a range of dance classes and has a good track record in raising the engagement of children broadly. The organisers are keen to provide other opportunities to their participants which improve their life chances and mathematics is the ideal candidate.

Practicalities

Gipton Together Summer Camp is held at Gipton Community Centre. The summer camp is very low cost, with no childcare available at remotely comparable costs. It is always oversubscribed. The centre has small rooms and a hall. It doesn't have much equipment to run talks or classes so we had to bring any equipment that we needed.

The audience was ready-made, in that the children were at the summer camp anyway. That said, the children had the option of not attending MathsWorldUK sessions.

The cohort was split into four age brackets with approx. 15 children in each group. We spent an hour with each age cohort each day and we ran four days. The participants are well known to the organisers. There were no physical disabilities in the group. The age range provided a set of accessibility issues - there was a broad range of cultures and English language skills represented. There were participants with ADD and ASD.

Given the range of abilities, interests and backgrounds we chose a hands-on set of activities which had scope for different levels of engagement. We had a minimum of 3 helpers for each session who collectively had a wealth of experience of working with children of all interests and abilities.

Day 1

- Ages 4 – 8 – Baking and making boxes from nets For many of the children this was the first time they had baked from scratch. They had to measure their ingredients. Whilst the cakes were baking the children made boxes from nets.
- Ages 8 – 16 Code breaking The older children were able to undertake code breaking activities starting with transposition ciphers and moving up to frequency analysis.

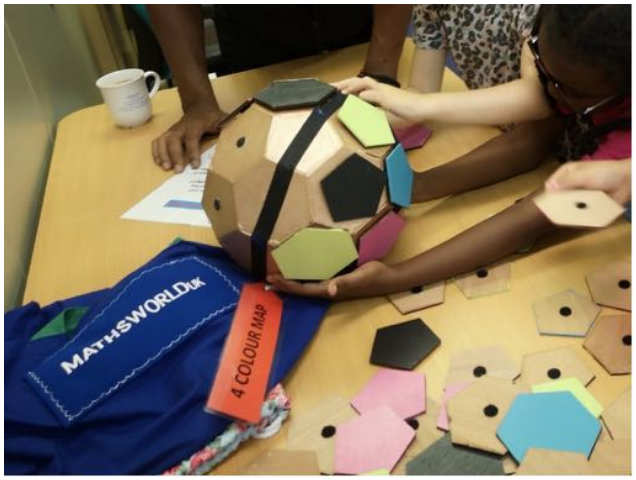
Day 2 Construction (for all ages)

Alongside 10 different commercial construction brands brands (Lego, Duplo, K-Nex, Straw and Connector kits, Agirlgle Stackers, Geomag, Mosaic Peg Board, Galt Marble run, Georello Gears, Cochranes Construction Straws) we took small groups to make a giant Leonardo dome collectively.

Building a Leonardo dome

Day 3 Problem Solving with MathsWorldUK equipment

Completing a physical sudoku



Working on a 3D version of the 4-colour map problem

Day 4 Problem Solving with Board games

Games, including Rush hour and Genius square

Evidence and Recommendations

This project was run without funding and so without a requirement for a formal evaluation or written report.

The children were sceptical that they could enjoy any maths session but they attended all four days and were clearly excited by the activities. We had been warned by the organisers that the children would be likely to drop out of our sessions which didn't happen.

We were given verbal feedback from organisers and the children that they had hugely enjoyed the sessions. The adults who assist at the community centre were also sceptical of mathematics but became very interested in our sessions. We were invited to attend subsequent years (which the pandemic has prevented).

Most of the problems we faced we had anticipated. These included a lack of equipment and the need for a lot of adult support with some activities. The rooms were not ideal but we adapted our activities to fit the space.

As we didn't formally evaluate the work there are questions which are unanswered including what the students learned and what their lasting impression was. It would be nice to run a similar activity and measure before and after impressions of how much they would engage with/enjoy the session.

More information

MathsWorldUK website: mathsworlduk.com

CASE STUDY 5

Pop Maths Quiz

Organisations involved: Sheffield Hallam University

Case study written by: Alex Corner and Jeff Waldock

Intended audience: Years 6 – 13 (Ages 11-18)

Maths content: Curriculum and curriculum-adjacent material for the above school years

Audience group: Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College, Primary or Elementary

Audience interest level : Uninterested, Receptive, Engaged

Topics: general maths, problem solving

Background

The Pop Maths Quiz was conceived as a means of widening the appeal of mathematics to young people, by creating a fun and engaging outreach event, raising their aspirations and potentially boosting applications to study the subject at university. A secondary benefit of holding the event within the University was to give the participants an experience of the university environment, perhaps helping break down the 'ivory tower' reputation it may have held for those who may not otherwise have aspired to apply. A third aim was to raise the profile of Mathematics at SHU within the local region.

Implementation

The event was designed in a 'pub quiz' style, where 20 mathematical problems, riddles, and puzzles are read aloud to students working together in teams spread across four age ranges: Year 6, Years 7-9, Years 10-11 and Years 12-13. In addition, following the quiz itself, a popularisation 'lecture' is given aimed broadly at Y9 students with 400 places available in the University's large lecture theatre.

Although intended as a 'fun' event, teams took the challenge very seriously and there was strong competition to take back the trophy awarded to the winning team. There were some issues with parents and or teachers standing too close to the teams and appearing to offer help, so it became necessary to separate the teams from adults who came with them. Schools wanted to practise quiz questions in advance, so there were many requests for previous years' questions. To try to preserve the fun element we had a policy of not releasing batches of previous questions, but provided some sample questions on the website. It also became quickly clear that it was of paramount importance to closely check questions for ambiguity, bearing in mind they are read out.

The activity was promoted by email from our events team to schools via existing contacts, and through the event website.

The first event took place 25 years ago in 1997 and it quickly gained in popularity to the point where the capacity of the University accommodation was reached, with upwards of 1,000 participants. In recent years unfortunately it has been postponed once due to hazardous weather and twice because of the Covid-19 pandemic.

Accessibility

Accessibility was borne closely in mind when constructing the questions. Schools understand the context of the quiz, but we provide additional readers to repeat questions to teams where necessary. Since the venues were all on campus, physical accessibility issues had been assured.

Evidence and recommendations

Schools, and individual participants, were asked to complete a feedback questionnaire describing what could be improved and what went well at the event. Questions included asking about the event itself, how well the staff and volunteers ran the event, and how engaging the invited speaker was.

The questionnaires often reflected how well the teams did overall in the quiz, with any more negative responses often allowing us to see whether we had unintentionally thrown in too many difficult new questions. Often the teachers would also ask whether they could have

old questions to practice with their students – we tended to explain that this wasn't in the spirit of the Pop Maths Quiz, which was geared towards the enjoyment of mathematics in and of itself rather than winning outright. However, we did acknowledge that offering a prize to the winning teams, as well as the framing of it as a quiz, encouraged the activity to be unavoidably competitive.

A further problem that we eventually ran into was the expectation to invite more well-known popular mathematicians, when in earlier iterations of the event it was more likely for a staff member in the group to deliver the Pop Maths lecture themselves. This led to problems trying to source funding in order to suitably pay the mathematics communicators that we invited.

A further issue was the not inconsiderable time taken to write (and crucially check) the 80 questions (plus tie-breakers) needed. Staff gave their time to do this, but we also liaised with staff running similar events elsewhere to share the load.

More information

A short video filmed at the Pop Maths 2014 event:
vimeo.com/90463076

Pop Maths website: waldock.org/popmaths

CASE STUDY 6

UK Mathematics Trust Competitions

Organisations involved: UKMT, University of Leeds

Case study written by: Howard Groves, Greg Chamberlain, Katie Steckles and Peter Rowlett
(This case study is written based on an interview with Howard Groves for this project; in the text, "I" refers to Howard.)

Intended audience: UK secondary school students

Maths content: Various

Audience group: Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College

Audience interest level: Engaged

Topics: General maths, Problem solving

The UKMT aims to advance the education of young people in mathematics, in particular, by organising and running mathematics competitions.

Origins of the Project

The original challenges were run by the UK Maths Foundation, which was run single-handedly for 8 years by a reader at the University of Birmingham. As the challenges grew in success, there was need for a bigger organisation, and the University of Leeds took it over in 1996. They employ a small admin team, but the rest of the organisation is made up of volunteers.

The first Maths Challenges took place in 1988, and there are now three levels of challenge - junior, intermediate and senior.

Practicalities

The test is delivered as a multiple-choice paper, with questions written out and a separate answer sheet. The papers are sent out to schools in advance, and while it does have to be done on a particular day, unlike public exams there's not a specified time.

Some schools enter whole year groups, while others hand-pick - most schools set by ability in maths, and maybe the top two or three sets might be entered, but it varies a lot between schools. Typically around 2500 schools enter the competitions each year, resulting in 250,000-300,000 students doing the junior and intermediate challenges, and more like 100,000 doing the senior challenge.

We give out certificates to the top 40% of participants. The top 7% get Gold, then up to 20% would get Silver, and between 20%-40% would be Bronze. Some schools might run it more competitively than others - it's up to the individual teachers. Our aim is to give them the sort of experience they don't normally get in the classroom - we put a bit of humour into it as well. For many students it's just 1 hour a year and probably soon forgotten, whereas those who go on to do follow-up exams or the mentoring scheme or summer schools can get a really positive experience from it. Many schools send details of successful candidates to local newspapers for publicity purposes.

There's also a junior and senior team challenge, where schools are represented by teams of 4 - they start off with a local round and can then qualify through to a national round.

While the administration of the competition itself - contacting schools, sending out the question papers, feeding them into the optical mark recognition machines and collating the results - is undertaken by the employed staff at the university, the mathematical work, setting the questions is done by a team of volunteers, consisting mainly of maths teachers and a fair number of university staff, most of whom are retired.

The content of the questions isn't necessarily anything harder than topics they might come across in their curriculum, but aims to enrich and show them different materials. There's very little technical stuff - it's more about problem solving, and hopefully more interesting. Even with a limited amount of technical ability needed, it's still possible to ask some really quite difficult questions.

Volunteers also form the board of trustees which sits above the admin staff, who are responsible for overall policy. The vast majority of our volunteers are very committed. I've been a volunteer since before UKMT existed - I actually wrote to complain about one of the questions on the papers, and was invited along to Birmingham and that's how I got involved.

Every year I organise a meeting where we set draft papers for the junior and intermediate challenges. We have to write new questions every year - it gets harder and harder!

For higher-performing candidates, there's a follow-up paper at each level which consists of longer questions - typically 6 on a paper for a 2 hour exam which require full written solutions. The marking for this is done by a team of 50-60 of us who get together in a hotel in Leeds and mark them over a weekend.

This is often a good way to find new volunteers for question setting - they come along to a marking weekend first. We also sometimes pick up volunteers when they bring a team along to the team challenges, and talk to our staff there about getting involved.

As well as the competitions, we also run a mentoring scheme for bright students who want to get more interested in maths, so they can be

paired with a mentor. We also run summer schools for the higher performing candidates. Usually a week long, we started with just one a year in Birmingham and now there are six, including a couple in Oxford and two or three in Leeds.

At the top of the pyramid, there's the International Mathematical Olympiad, held every year with teams of 6 from about 150 different countries. We've hosted that twice - Glasgow in 2001, and Bath in 2019. The highest performing challenge participants can make it into the team for the Olympiad, via follow-up papers and quite an exhaustive selection process - it's not the ultimate goal, but for higher performing candidates the GCSE syllabus doesn't do them justice at all, and it's an opportunity for them to see that there are far more interesting things in mathematics than what's on the syllabus.

The UKMT is funded partly by sponsorship, but nearly all of the money comes from the fees we charge schools to enter their students in the challenges. We try to keep the fees as low as possible, but it subsidises all the other activities, including the summer schools, Olympiads and camps. We also publish a yearbook every year with problems from the challenges, as well as a set of books of problems collated by topic at different levels. A lot of parents buy them for their children who are interested in maths, and we make quite a bit of money from selling them.

Accessibility and diversity

The challenge papers are sent out to schools well in advance, and are in the form of 4 sides of A5, so teachers can enlarge them for pupils who need a large print version. We also offer large print versions of the paper and braille papers for free as well as a speech function on our online questions.

Since there's a requirement for a school to have a teacher keen enough to run the challenge, it's hard for us to reach all schools. If we don't get an entry from a school one year then the staff at Leeds follow it up. Schools pay to enter the challenge, but UKMT have tried initiatives such as offering free entries, and sending sample materials. The collected books of problems are also a good resource for schools - teachers don't have too look to hard for materials to interest the brighter pupils.

The summer schools are heavily subsidised to make them available to as many people as possible, and if someone had been invited and couldn't afford the fee, I'm sure UKMT would be prepared to help financially if their school couldn't.

The people who do the invitations to the summer schools try to get a reasonable balance in terms of gender and other factors. We ensure that half of all summer school students are girls and aim to have 80% of students coming from state schools. In the last 5-6 years at least, one of the Summer Schools we ran at Oxford was for girls only. Since we get lower numbers of girls in the International Mathematical Olympiad team - it's rare to have a team of 6 boys, but generally there are only 1 or 2 girls - we started a European Girls' Mathematical Olympiad in 2012, and now other countries are involved with that as well.

Challenges, Evaluation and Improvements

Since the challenge can be completed any time during the specified day, it has become more difficult to administer, with the advent of social media - particularly with the intermediate and senior challenges. There are chat rooms where candidates can discuss a paper when other schools won't have seen it. We do liaise with the people who run those chat rooms and try to discourage them from putting anything up before the end of the school day, to try and keep some sort of confidentiality.

Up until this year we had a system to discourage guessing - the paper was organised so that the first 15 questions had no penalty for a wrong answer, but for the harder questions 16-25 you could lose marks for wrong answers. We wondered if this might be disproportionately impacting girls, since our experience has been that generally, they can be less adventurous and more reluctant to guess.

We decided to implement a trial this year in the Junior maths challenge held in April to do away with that negative marking system so there would be no penalties for wrong answers. This was very difficult to implement, largely because of COVID. We had some candidates sitting the Junior Challenge in schools, some doing the paper online in schools and some doing the paper online at home, where we could not be sure that they did not receive any help and did not use a calculator. This made it impossible to draw any conclusions from the trial.

We do evaluation via a survey following each Challenge and one at the end of the year with all schools that take part during the year. We get some feedback from teachers and students about the materials and most of what we get is positive. Occasionally a teacher will say "I don't think that was accessible, it was using terms my candidates didn't understand" - because we're volunteers, we're limited in what we can do, but we can take it on board.

We also look at the results of each year's Challenges, particularly the statistics showing how well individual questions were answered, at problem group meetings before setting the following year's papers.

One other part of our evaluation is numbers from year to year - when UKMT started it grew quite rapidly, but it's plateaued over the last few years with some variation. We've also got a much broader range of activities than we started with - when the UKMT was set up in 1996 all we did was run the 3 maths challenges, the follow-up papers (including those which led to the training and selection of the team to represent the UK at the International Mathematical Olympiad) and one summer school a year. Since then we've added the team challenges, more summer schools and the mentoring scheme.

More information

UKMT website: UKMT.org.uk

CASE STUDY 7

Sheffield Hallam University Girls in Maths day

Organisations involved: Sheffield Hallam University

Case study written by: Claire Ketnor and Angharad Ugonna

Intended audience: Girls in years 9-10 from the local area

Maths content: Various (including Cryptography and Mathematical Modelling)

Audience group: Lower secondary or Middle school, Upper secondary or High school

Audience interest level: Uninterested, Receptive, Engaged

Topics: Codes and cryptography, Mathematical Modelling

Origins of the Project

Significantly fewer girls than boys choose to take A-level Maths (FMSP, 2016). The Girls in Maths day aims to inspire more girls to take Maths beyond GCSE level. It's an outreach event for up to 100 girls from local secondary schools. It is run at least once a year by staff and student ambassadors from the BSc Mathematics course at Sheffield Hallam University.

Practicalities

The university's outreach team send out adverts to local schools to promote the event. Typically each school involved brings around 15 girls in year 9 or 10.

The day consists of the following:

- An introduction;
- A Modelling workshop;
- A cryptography workshop;
- A mini campus tour by a student ambassador;
- Lunch whilst playing games from the Maths Arcade;
- An inspirational talk by an external speaker.

Throughout the day, there are opportunities for students to become inspired by the subject and have their confidence boosted.

Evidence and Recommendations

The following comments and results are from the evaluation of the January 2019 Girls in Maths day. When asked within a survey at the end of the day, 93% of the pupils said they enjoyed the event. When asked what they thought of the day, words used by the pupils included "engaging", "enjoyable", "interesting" and "inspiring". Other comments included the following:

- "Eyeopening"
- "Maths isn't as boring as I thought"
- "Changed my mind about uni"
- "Allowed me to think of the future"
- "Made me like maths more"

23% of the pupils said that they planned to study A-level Maths before the Girls in Maths day, whereas 53% of the pupils said at the end of the day that they would consider it. Due to most pupils being in Year 9 and the first Girls in Maths day being in 2018, it's too early to see whether there has been any effect on A-level choices.

A reason provided by one of the teachers for bringing pupils to the event was "to inspire them to continue onto higher education". Other comments from teachers included that the event was "good to promote maths to girls", "a good idea to create interest" and "inspiring".

Having student ambassadors involved is a great opportunity for the secondary school pupils to have conversations with current students. Having a mini campus tour is well received as it gives the girls the opportunity to see some of the facilities whilst having a break from the activities, and breaking up the day into smaller activities helps to keep the attention of the pupils.

More information

Blog post about a Girls in Maths event in January 2019:
blogs.shu.ac.uk/outreach/2019/01/24/girls-in-maths

SHUMaths Twitter: twitter.com/shumaths

CASE STUDY 8

Women in Mathematics Research Outreach Event

Organisations involved: University of Manchester (School of Mathematics) and the Advanced Maths Support Programme; Dr Demi Allen, Abigail Bown, Catherine Bruce, Dr Elizabeth Buckingham-Jeffery, Professor Louise Walker

Case study written by: Dr Demi Allen

Intended audience: Year 12 school students

Maths content: Various

Audience group: Sixth Form or Junior College

Audience interest level: Receptive, Engaged

Topics: General maths

Image from the 2019 event in Manchester

Origins of the Project

Although the number of young men and women studying mathematics at university is balancing out, it is still the case that fewer than 10% of mathematics professors in the UK are female. To inspire young women to consider a career in research mathematics we organised the first "Women in Mathematics Research" day for local year 12 students hosted at the School of Mathematics at the University of Manchester in June 2018. The event was open to all students, regardless of gender, but for the reasons above we were particularly interested in encouraging female students.

To showcase successful female role models, all of the speakers and volunteers at the event were female mathematicians. The event included plenary talks by Professor Victoria Gould (York) on "My Career as a Mathematician" and Dr Isobel Falconer (St Andrews) on "Female Mathematicians Throughout History", and concluded with a keynote talk by Dr Helena Stage (Manchester) on "Rationalising Chaos". In addition, there were several parallel workshops run by local and external mathematicians at different stages of their careers relating to aspects of their research. The students were free to choose which workshops to attend and time was also factored in to the workshops for the mathematicians to say a bit about their careers so far and allow students to ask them questions.

Practicalities

The funding sources for the initial event in Manchester were: * Dr Demi Allen's EPSRC Doctoral Prize Fellowship Outreach Budget, * Dr Elizabeth Buckingham-Jeffery's Prize money from the 2017 "I'm a Scientist get me out of here" competition, * Dame Kathleen Ollerenshaw Outreach Funding, * Further Maths Support Programme (now Advanced Maths Support Programme).

The event was hosted at the School of Mathematics at the University of Manchester and the day began with a brief introduction to the event from Professor Louise Walker. This was followed by two plenary talks. The first of these was "My Career as a Mathematician" given by Professor Victoria Gould from the University of York, who talked mainly about her career (the journey to professorship) and pursuing mathematics to higher levels beyond school. The next talk was on "Female Mathematicians throughout History" and was given by Dr Isobel Falconer from the University of St Andrews. Isobel talked about some lesser known female mathematicians who had made some great contributions despite often being faced with rather challenging circumstances. Rather sadly, some of the mathematicians Isobel discussed had essentially been written out of history because they were women.

After the first two talks there were several workshops on different areas of mathematics presented by female mathematicians from various places and at different career stages. The students picked which ones they wanted to attend and each workshop was given to smaller groups of 5-10 students.

The day was ended by a final plenary talk on some applied mathematics entitled "Rationalising Chaos: A mathematical approach to the untameable". This final talk was given by Dr Helena Stage who at the time was a PhD student in the School of Mathematics at the University of Manchester.

One of the things we asked all of the speakers to do (for plenary talks and workshops) was to devote a little bit of time to discussing their career so far and to allow students to ask them any questions about that.

The event was advertised by Abigail Bown (the local AMSP area coordinator) advertising to her school contacts with a couple of our personal contacts also used to reach out to a wider range of schools. In the end there were around 45 students plus around 10 teachers from in and around the Manchester area at the event.

Catherine Bruce (PhD student at Manchester and co-organiser of the event) leading a workshop on fractals

Similar events were organised in 2019 again at the University of Manchester (for year 10 and year 12 students) and at the University of Bristol (for year 12 and 13 students). In 2020 the events were postponed/cancelled due to the COVID-19 pandemic, but there was an online event in 2021, organised by Abigail Bown at the University of Manchester, which was an iteration of the original Women in Mathematics Research event.

Evidence and Recommendations

The aim of this event was to inspire (particularly female) students that a career as a research mathematician is something they can aspire to. We used a standard AMSP feedback form to collect feedback from the participants.

In addition to learning about areas of mathematics not encountered at school, the students really appreciated "being able to ask lots of individual questions" due to small group sizes. When asked what the most useful aspect of the day was, one student said "hearing about women who have achieved something in worse conditions than we have nowadays has inspired me to handle being in a male dominated job" while another commented on "meeting all these amazing mathematicians" and the "empowering atmosphere!".

More information

Details of the 2019 event on the University of Manchester website:
www.manchester.ac.uk/discover/news/manchester-hosts-women-in-mathematics-research-event

Information about the 2019 event in Bristol:
sites.google.com/view/wimr-2019/schedule

CASE STUDY 9

Bletchley Park - Past, Present, Future: Cryptography

Organisations involved: Bletchley Park, Tom Briggs

Case study written by: Tom Briggs

Intended audience: Adult, non-specialist members of the public

Maths content: Codes and codebreaking, History of Cryptography

Audience group: Adults, Retired

Audience interest level: Receptive, Engaged

Topics: Codes and cryptography, History

Origins of the Project

Past, Present, Future: Cryptography was a standalone (but repeatable) activity intended to "test the waters" regarding the desire for, and enjoyment of, events marketed at the general public that were developed using ideas, experiences and skills usually reserved for Bletchley Park's formal education programme.

I had long entertained an idea of some sort of "codebreaker training course" accessible to people who were interested in finding more about how codes and ciphers work, but who did not necessarily see themselves as a "maths person". The event was aimed at adult, non-specialist members of the public with an interest in codes, ciphers and Bletchley Park.

Practicalities

The events were "full day" courses lasting from 10:30 – 15:30 with attendees expected to stay all day. The events took place on site at Bletchley Park in Block B, and the ticket cost (£10.30) included a day pass to visit the rest of the site.

Bletchley Park, Block B (Image from Google Streetview)

The first session ("**Past**") presented them with a locked briefcase and a booklet of puzzles. An introductory puzzle was projected at the front of the room. Completing this told them how to get started on the rest.

The puzzles were all based on real codes and ciphers, and were accompanied by historical notes with a quick overview of their background. Tips and codebreaking tricks were dished out, many of which are mathematical in nature and link to areas of mathematics that many participants remembered from their school days.

The second session was a tour around Bletchley Park to put the rest of the day into its historical context.

The third session ("**Present**" – that is, the present as far as BP's codebreakers are concerned) was built around using information gathered from the first session to learn about how an Enigma machine works, using a simulator to decode a message "received" at the beginning of the session, and utilising some of its weaknesses to find missing settings.

The fourth session ("**Future**" – from the point of view of the WW2 codebreakers), following a lunch break, follows postwar developments in cryptography, culminating in a section which takes participants through encrypting and decrypting a message using a simplified version of RSA encryption by hand. A discussion of some of RSA's apparent weaknesses built up to a (very) brief look at quantum cryptography.

Accessibility

The assumption was made when producing the course that most participants would have had no experience with codes and ciphers in the past. Care was taken to produce resources with accessible print sizing, and larger-print versions were available if requested.

Activities & questioning were included from the beginning that played up to common misconceptions, inviting common incorrect answers

from participants (e.g., "what is Morse code used for?" usually prompts a response along the lines of "keeping secrets.") These incorrect responses were praised and encouraged, and it was often the case that most participants thought the same thing. This was used to reduce anxiety around "getting the answer wrong" which often causes people (particularly adults!) to be reticent about joining in.

Evaluation

Evaluation of the project was achieved by handing out evaluation sheets and encouraging participants to fill them in, largely as an exercise to determine the commercial viability of developing the series further (i.e. did participants feel that the experience was worth paying for; would they be prepared to pay the same amount for a "sequel") as it was necessary to justify learning activities against this metric to get approval from the organisation's leadership.

As educators in an environment heavily geared towards income generation, pedagogical merit was highly important to us, but leadership generally responded to assessments of educational (rather than financial) worth with indifference, so evaluation on this side of things was done mainly for our own benefit and, to a certain extent, conducted "under the radar": There was a free-text response on the evaluation sheet which we encouraged participants to use to make general statements about their experiences through the event, and comments such as "I hadn't realised maths could be so much fun/ interesting" were common.

We also made an effort to engage with participants individually, and received many positive comments regarding the content, delivery and general theme of the event. At the end of each event we made it clear that participants were welcome to stay and ask questions should they have any, and while most left at that point, up to a quarter of the participants stayed behind for different lengths of time.

Many had more probing questions about the Enigma machine that was used during the event; some wanted more specific references to further reading than the general books and websites we recommended during the sessions; a few had more specific tales and observations. One memorable example was a person who signed up because they worked in a lab next to one researching quantum cryptography, and wanted to understand more of the background.

More information

Bletchley Park website: bletchleypark.org.uk

CASE STUDY 10

Mathstastic workshops at Life Science Centre

Organisations involved: Life Science Centre

Case study written by: Noel Jackson

Intended audience: Schools - KS2 upwards

Maths content: Hands-on activities across a wide range of mathematical topics

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College

Audience interest level : Uninterested, Receptive, Engaged

Topics: Codes and cryptography, magic, number, hands-on

Origins of the Project

The Life Science Centre developed a suite of hands-on workshops to deliver all aspects of the primary science curriculum. It was recognized that similar offer could be developed for Maths.

The first stage was to assess what was offered by other centres in the UK, Europe and beyond. The activities that appeared to be most popular and successful with students were:

- Maths Shows, as exemplified by the show offered by Techniquest in Cardiff.
- Large scale maths puzzles - for example those at Cape Town Science Centre
- Team challenges rather than individual activities

What did not work were exhibits adopting a historical approach and, "games" where students completed ordinary paper calculations to move round a board.

There are two key aspects of successful engagement. The first is the degree of fun inherent in the activity and the hooks to draw in the target audience. The second is the relevance of the maths illustrated. The ideal activity combines both so participants see it as fun and relevant. Most importantly, successful activities have a low threshold so all students feel that they can participate but have a high ceiling so that the most able students benefit appropriately. Some centres wish to demonstrate the beauty of maths as an intellectual construct but this is most likely to appeal to an audience who are already maths literate and well-disposed towards the subject.

Practicalities

The initial Mathstastic offer consisted of a package of a circus of puzzles and games, an hour-long extension activity and a maths show. In the original "0.07 Maths Show" students found how ability in Maths was essential for a successful spy, helping them escape when tied up, enabling them to crack codes and know when their messages had been intercepted and corrupted. Because the Life shows started to use more elaborate stage sets which were difficult to alter, it became increasingly difficult to create the right atmosphere in the theatre. The 0.07 Maths Show has now been replaced with an Astronavigation workshop in our planetarium. We now have well over 30 extension activities but by far the most popular is using modular numbers to complete some impressive card tricks with a deck stacked in Sy Stebbings order.

The initial offer is still available on demand but there are now three times during the year where the offer is as expanded into a whole day. In early November there are sessions for small groups of more able students. These include an introduction to maths trails and an opportunity for teams to develop questions of their own that they think would interest other students of their age. These sessions have the bonus of providing CPD and exemplars of good practice for the staff that accompany the students.

A further extension to Mathstastic has been working with the maths education departments of Newcastle, Durham and Sunderland Universities for the Festival of Maths in early February. Groups of trainee maths teachers are challenged to develop a 25-minute maths extension activity which participating classes visit as a circus over the course of a day. Support for the student teachers is given over the course of Autumn Term as they are encouraged to use their imagination to develop an exciting hands-on way for young people to gain insight into a particular topic. The excitement with which the young people engage with the activities throughout the day is generally a sharp contrast to the trainee teachers' experiences in school and a powerful advertisement for adopting a hands-on approach to maths teaching.

The last part of the Mathstastic offer is Mathsplosion, an event for GCSE students which Life runs with the AMSP. The schools are recruited and funded by AtHM and extended activities are offered by both Life education staff and external maths consultants.

Evidence and Recommendations

Feedback is collected from all Mathstastic participants including both teachers and pupils and across the board it is overwhelmingly positive. Casual observation shows that the students participate in and enjoy the activities throughout the day and teachers often comment positively

on their persistent engagement. Student comments generally focus on the enjoyment although the practical use is also recognized. The only poor feedback we get is from occasional small groups of teenage boys, very often those who have had to be reminded about their behaviour by their teachers.

The feedback from all Mathstatstic activities is positive and schools who participate generally make repeat visits each year. The main problem is getting maths teachers to come the first time. We understand that Maths teachers are necessarily self-sufficient and the idea of visiting a science centre to enhance maths is not self-evident.

Cost is a barrier for some schools. The Life Science Centre is not funded by the government, local authority nor any external agency. As a consequence, the cost of activities and their delivery have to be covered. However, finding the time to attract a grant sufficient to fund a five year programme for Festival of Maths would take up more time than the Life team have available.

With regard to the Festival of Maths, perhaps the most telling evidence is that the current maths lead in the education department at Sunderland was a participant in the very first festival when she was a PGCE student at Newcastle. She ascribes her success in getting students to engage with maths to a teaching style based on the lessons learnt at the Festival.

There is still a general reluctance among science centres in the UK, Europe and America to engage in mathematics. There is sometimes concern that the public will find maths uninteresting and find topics such as dinosaurs, robots and space much easier to sell. As a result, the small number of specialist maths museums (Mathematikum, Geisen; MoMaCa, Barcelona and MoMath, New York) have set up their own network with conferences alternating annually between Europe (Matrix) and New York (MOVES). This is a shame as Matrix/MOVES provide focus for an enormous amount of mathematical expertise whereas the science centres have a well-established network of centres with large audiences and staff experienced in hands-on learning. Working together more effectively would create activities that were so much greater than the sum of their parts.

More information

Life's Education programme website: life.org.uk/education

Twitter account: twitter.com/scienceatlife

CASE STUDY 11

Royal Institution Mathematics Masterclasses

Organisations involved: Royal Institution of Great Britain

Case study written by: Rachel Dorris

Intended audience: School students (mainly 9-10 year olds and 13-14 year olds, but often working with other age groups)

Maths content: General maths – enrichment, so not linked to school curriculum

Audience group: Primary or Elementary, Lower secondary or Middle school

Audience interest level: Receptive, Engaged

Topics: general maths, problem solving

Origins of the Project

The Ri Masterclasses were founded in 1981, on the back of the 1978 Christmas Lectures delivered by mathematician Sir Christopher Zeeman. Zeeman's Lectures, 'Mathematics into Pictures', was the first set ever done in mathematical topics. The BBC, who televised the lectures, had grave reservations at the time about him adding complex mathematical theory and proofs into the lectures. Despite this, Zeeman persevered and his Lectures were extremely well received by the public. As a result, a task force at the Ri was set up to find a way to establish a maths outreach programme and create a legacy for the 1978 Christmas Lectures. The Mathematics Masterclass programme was born from this, and has been running ever since. Initially for year 9 students in London, it soon expanded across the UK and to different age groups. Ever since 1981, we have been striving to maintain Masterclasses as a space where school students can explore complex mathematical concepts in an inclusive but not 'dumbed down' way.

The Masterclasses are a course of 6 interactive workshops that run throughout a school term, bringing students together from different schools in communities. The workshops are delivered by volunteer STEM experts from academia, education and industry. Students join Masterclasses because they have an emerging interest in mathematics – our aim is to nurture this interest through fun and challenging activities, develop confidence and signpost to potential futures that include mathematics and other STEM subjects.

Aims and Objectives

The Ri Masterclasses for primary and secondary school students aim to contribute to a positive shift in attitude towards STEM (science, technology, engineering and mathematics) subjects by inspiring and enthusing students, allowing them to investigate a range of ideas and applications.

We are meeting the challenge of inspiring and nurturing young scientific and mathematical talent by:

Providing a free STEM enrichment offer to schools and students

Providing extended engagement over a course of workshops to engender long-term attitude change and increased confidence

Providing hands-on, interactive sessions so students play an active role when learning content

Capturing students at an early and critical age

Expanding students' knowledge about the multiplicity of STEM disciplines and the diversity of their applications

Providing diverse and positive role models to champion these fields and careers

Deepening understanding of jobs and career opportunities

Encouraging and developing students' aptitude and promoting ongoing engagement

Demonstrating the relevance, excitement and value of STEM subjects in society, identifying real-world applications as they explore the subjects

Enabling students to meet like-minded peers from different schools, backgrounds and local area

Practicalities

Masterclasses are extended outreach activity for school students. Implementation practicalities include:

Practicalities of coordinating a nationwide network of volunteers:

Fundraising to cover cost of Ri staff, allowing us to develop a UK-wide network of volunteers and collaborators who run Masterclasses in their communities across the UK that are free for schools and families

Managing the programme of volunteers – ensuring we adopt governance best practice (safeguarding and data protection being at the fore); maintaining our volunteers e.g. communicating with and rewarding volunteers; recruitment and training of new volunteers as the programme develops.

Practicalities of delivering a Masterclass series:

Recruiting school students via schools - developing contacts with mathematics teachers and sending them nomination forms; they then select the students they feel would most benefit from this opportunity

Recruiting and training speakers to lead each workshop – we require the workshops to be interactive with plenty of student-led investigations, and not linked to the school curriculum

Booking a venue that is suitable for accommodating a classroom of school students

Safeguarding and pastoral care of students – arranging supervision of the Masterclasses by someone who is trained at undertaking pastoral and safeguarding duties

Handling the logistics of running each workshop – supporting the speaker and supervisor to ensure all materials are prepared, and ensure a safe and fun experience for all

For Masterclasses, teachers are the 'gate-keepers' to our audience of school students. We work with groups across the UK who have built up networks of school contacts for outreach purposes e.g. universities, maths education support networks etc. We also contact schools directly to offer Masterclass opportunities.

To promote Masterclasses to new communities, we spread the word through Royal Institution education newsletter and comms (social media etc). Ri staff also attend education conferences to promote Masterclasses, and we collaborate with other organisations (such as the Ogden Trust). We also make use of membership of professional and education groups (such as the Mathematical Association) and word of mouth.

Accessibility

Accessibility has been built into the Masterclass programme in the following ways:

Masterclasses are free for schools and families

We have been running online Masterclasses during the pandemic, and will be continuing this offer to allow students to join who are unable to attend in-person - we recognise that travelling to 6 Masterclass sessions is often a barrier to participation for a variety of reasons

Many primary Masterclasses are run during school hours and small groups of students are taken by an attending staff member (as they would for any school trip) to the Masterclasses - this removes barriers that families may experience from getting their offspring to Masterclasses every week

We train speakers in EDIA practices, regarding how they interact with the students, how they present diversity in their material, how they ensure material is accessible

Masterclass organisers gather information from each student in advance of Masterclasses regarding additional support they might need, and liaise with their parent/career directly and work with speakers and supervisors in the run-up to each workshop to ensure individual needs are met.

Evaluation

Impact is evaluated at the end of each Masterclass series using student questionnaires and evaluation by Ri staff during visits to the series. The Masterclass team uses the data to monitor quality, addressing issues raised about venue, supervision, delivery of the workshops, etc.

There have also been nationwide evaluation programmes and impact assessments undertaken in 2008 and 2018.

We released an Impact Report in 2019, which shows the positive impact of the Masterclass Programme on the students who take part each year.

More information

Ri Masterclasses website: rigb.org/learning/ri-masterclasses

CASE STUDY 12

Think Maths - schools talks and workshops

Organisations involved: Matt Parker, Zoe Griffiths, Stand-up Maths Limited, Think Maths

Case study written by: Zoe Griffiths and Katie Steckles

Intended audience: School students ages 9-18

Maths content: Variety of maths enrichment topics

Audience group: Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College

Audience interest level: Uninterested, Receptive, Engaged

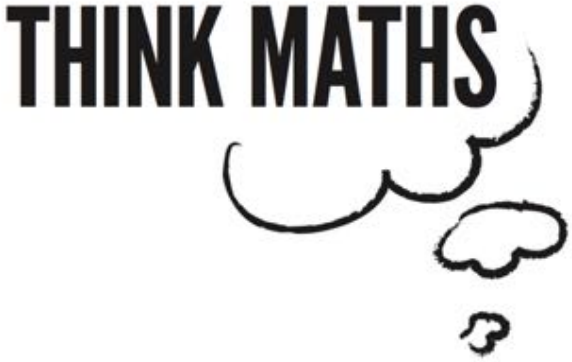
Topics: General maths

Origins of the Project

Think Maths was founded by Stand-Up Mathematician Matt Parker in around 2012. A former teacher, Matt developed content to go into schools and deliver engaging mathematical enrichment talks and workshops to school students aged 9-18.

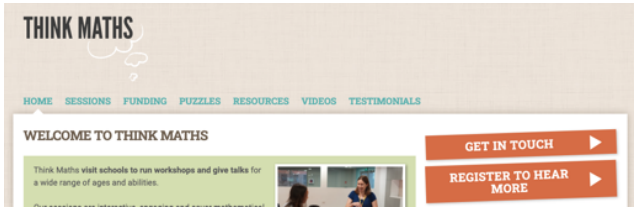
Matt has since recruited other maths communicators to take these sessions into schools themselves, including Zoe Griffiths, Katie Steckles and several other maths postgraduates and researchers. Many of the presenters have used their time with Think Maths as a starting point for careers in maths, outreach or education.

The Think Maths talks and workshops were initially designed by Matt, and are now also developed by the other speakers on the delivery team. Inspiration for interesting topics can be taken from popular maths books and YouTube videos. We aim to include tricks, games or other elements of interactivity that demonstrate the topics in question.



Practicalities

In order to facilitate bookings by schools, we built a website and developed materials with more information about what we offer; an admin system was put in place to field enquiries and make bookings, and to ensure the smooth logistical running of delivery.



We hired a freelance web developer and graphic designer to build the initial website and develop branding, and the website has a built-in content management system we can use to make updates.

Our sessions need to fit conveniently into a school's lesson slot. This changes from school to school, so some degree of flexibility is required. It was important to develop sessions with a plan for what material can be added in or removed at the last minute, and our sessions can run from 40 minutes up to an hour as needed. Schools can book up to four one-hour sessions in a day, which can be a mixture of talks and workshops to groups of different sizes.

We're aware that students are different in every school, and our speakers prepare sessions based on information we receive in advance (for example, the attainment level of students) – but equally important is the ability to quickly gauge the audience and make small adaptions during delivery to suit the audience in front of you. Therefore, sessions also had to be developed with this in mind.

For some of the Think Maths sessions (in particular, a session involving

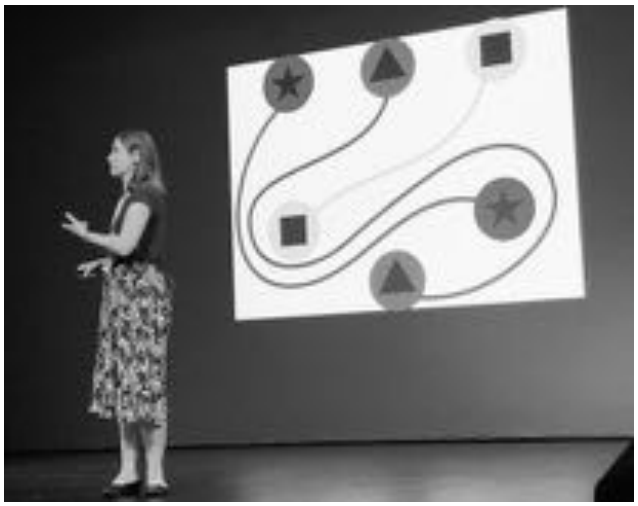
a smoke machine) there are hazards beyond normal classroom risk, so risk assessments have to be written and practical actions (for example isolating the smoke alarms) taken by the school, in coordination with us. This information is sent to the school once the choice of sessions is confirmed.

To promote our work, Think Maths has a newsletter, website, Twitter account and Facebook page, and the newsletter is sent out several times a year with details of related events, resources we've developed for teachers to use, and ways to book Think Maths speakers (including details of funding schemes they can apply for to cover the cost of a visit).

Largely, schools hear about us because they know of Matt's work on YouTube, as an author or as a performer in theatre shows. Also, a large proportion of referrals are by word of mouth from other schools who know of our work.

Accessibility

As part of developing our sessions, we've incorporated best practice into our slides and visuals – for example, ensuring our choice of font and background colours, and font sizes, are accessible. Our presenters always request a microphone for large audiences, and make sure that everyone can see and hear any demonstrations clearly. Schools can advise us of any specialist accessibility requirements when they book (or on the day, if the adjustments needed are more minor).



Evaluation

We send schools a teacher feedback form after each event. This allows us to gather statistics about how many schools felt the students benefited from the events, and how many schools intend to do follow up with their students based on the event. In that feedback form we also gather qualitative feedback designed to improve our product – schools can list things they thought went well and improvements they would like to see.

The project is on-going so we are constantly learning! Our feedback process (and our conversations with schools at the events) has helped us refine our sessions so they are as engaging and educational for students as possible.

We've learnt about potential pitfalls with the administration of bookings, and have tweaked our system in response to that – for example, we send a form for the school to provide the information we need for the booking (group sizes, ages, timings, school address, session titles etc) so the teacher can fill it in, and we can ensure this is all confirmed and communicated to the presenters ahead of the event.

More information

Think Maths website: think-maths.co.uk

CASE STUDY 13

New Scientist Puzzle Column

Organisations involved: New Scientist magazine

Case study written by: Rob Eastaway

Intended audience: New Scientist's readership is heavily centred on the scientific community, but the magazine is read by a diverse adult audience who are interested in science. More than half of the readership is overseas (particularly the USA). The magazine is taken by many school libraries, and is probably read by thousands of UK teenagers during term time.

Maths content: The puzzles are pitched at a mathematically literate audience, but do not assume knowledge of A Level maths.

Audience group: Young Adults, Sixth Form or Junior College, University Students, Adults, Retired

Audience interest level: Engaged, Expert

Topics: Puzzles, Problem Solving

Puzzle #09: The Cake and the Candles

Background

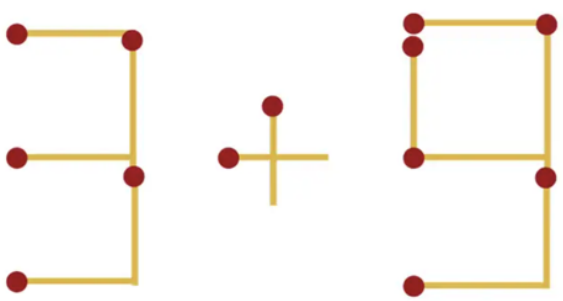
New Scientist ran a column called 'Enigma' for over 30 years. Enigma was axed in 2013, the editor commenting at the time that it had become 'a minority pursuit'. A glance through the later Enigma puzzles shows why it had fallen out of favour: the problems were contrived, long-winded with few 'aha' short cuts, and (for the lay reader) dull. Too many of them involved searches for a professor's telephone number that had some combination of prime/square/palindromic properties. Enigma had got to the stage where puzzles were being published in the hope that 'maybe somebody out there enjoys these things'. I would be surprised if more than a couple of hundred people seriously attempted Enigma each week.

In 2019 the magazine went through a redesign, and the new editor wanted to bring back a puzzle page. I was approached because of my previous involvement with New Scientist. The Features Editor and I discussed what 'type' of maths puzzle might be introduced. We knew that it needed to have much broader appeal than Enigma and we agreed a baseline condition: the magazine should only publish puzzles that at least two New Scientist journalists (who are generally NOT mathematicians) would want to have a go at themselves. After all, if the New Scientist staff don't care about the content, why should their readers?

Other criteria we agreed on were:

- Make the puzzles look as little like a school maths question as possible (achieved, for example, by wrapping the problem in a whimsical setting)
- Puzzles should occupy a mathematically competent reader for at least five, and preferably 15 minutes.
- The lay-reader should feel enticed to 'have a go' even if they don't get the solution.
- Puzzles should ideally have only one solution. Avoid puzzles of the 'how many ways can you find…?' type.
- Where possible, puzzles should involve some humour and have surprising answers.
- Have diversity in the names and genders of the characters that feature in the puzzles.

Implementation



Puzzle #57: Matchstick Magic

We have reached out to numerous people in the maths community in the hope of building a diverse pool of puzzle setters. Most puzzles that

are submitted need a little work, to tighten the wording or meet the criteria above. All puzzles are tested out on members of an informal network of puzzle enthusiasts. A puzzle will not be accepted in New Scientist unless it is 'liked' by the features editor, by me, and at least one member of the checker-network.

Evidence and Recommendations

There is no formal feedback on the New Scientist puzzle, but the column seems to have gone down well with New Scientist readers (one measure of this is the absence of complaints!)

New Scientist's readership does not include many maths teachers, but I frequently share the puzzles on Twitter and they are popular, more than 10% of views resulting in engagement. A couple of the puzzles have had over 10,000 engagements on Twitter. The puzzles often generate Twitter discussion, from maths teachers and the wider community.

The relative popularity of the New Scientist puzzles compared to (say) the now defunct Puzzle for Today (on Radio 4's Today programme) emphasises to me that, when attempting to reach an audience beyond the classroom, it's important for puzzles to have an engaging or humorous context, and to involve 'interesting' mathematical ideas, rather than routine procedures.

More information

Puzzles up till June 2020 were published on New Scientist's website (newscientist.com/article-type/puzzles), though I believe a subscription is needed to read the full puzzle and the solution.

I wrote a blog about the difference between 'puzzles' and 'maths questions' which is relevant: robeastaway.com/blog/puzzle-maths

CASE STUDY 14

Writing books

Organisations involved: Matt Parker

Case study written by: Matt Parker, Peter Rowlett, Katie Steckles and Greg Chamberlain
(This case study is written based on an interview with Matt Parker for this project; in the text, "I" refers to Matt.)

Intended audience: General public

Maths content: popular maths

Audience group: Upper secondary or High school, Sixth Form or Junior College, Young Adults, University Students, Adults, Retired

Audience interest level: Receptive, Engaged, Expert

Topics: General maths

Origins of the Project

I have written two mainstream science communication/popular science books: *Things to Make and Do in the Fourth Dimension* and *Humble Pi*.

Before this, I co-authored a book self-published by Queen Mary of London when I was working there about using magic tricks to teach mathematics. That was great fun - like a mini-version of writing a book as a practice run.

I enjoyed this and took on my first mainstream book as an exciting challenge - I wanted to give it a go and find out if I could do it. But there are two other key motivations for me.

First, I sometimes have ideas that are too long to make into a video or stage talk. Writing a book is the ultimate long form approach where you can build up complex ideas or arguments or whatever you want to do.

Second, a book is a whole new audience. A big part of the appeal for me is that the book will sit on shelves in book shops and people can stumble across it in a way that they can't with anything else that I do. People will recommend it and pass it around, and the way it's promoted brings it to a whole new audience. And then it gets translated and sent around the world, so the reach is different and unparalleled.

In terms of audience, *Things to Make and Do in the Fourth Dimension* is a bit nerdier, whereas *Humble Pi* is easier reading. That was a conscious decision, I wanted *Humble Pi* to be for people with no maths background knowledge and people who are just generally interested in things. At the same time there has to be enough in there to cater for hardcore nerds.

Practicalities

The publishers want to know if there's an audience for the book and whether the author has a bit of a platform already, so I had a lucky rolling start with that. If you're starting from scratch, you've got to convince publishers that there's an audience for what you want to do.

Having written for newspapers is what did it for me; that's when literary agents started contacting me because they are always looking for where the next authors are going to come from. A literary agent is incredibly important in the process because publishing is a very antiquated and publishers are big industrial machines. The publisher does not have the author's best interests at heart so you need someone who knows this ridiculous system and is on your side. Publishers will accept manuscripts directly and approach authors out of the blue, mainly because they want to get a cheap book, but they generally use literary agents as a filter.

So I started by having a chat with some agents. The agent is your first editor and will continue to be actively involved in the writing of the book - in fact, your book will be heavily edited by several people who aren't you.

Then you work up a proposal that includes a sample and an outline of what the rest of the book will be. For first time authors, you might write a chapter or 10% of the book - I wrote about 10-15 thousand words - which demonstrates you can write long form. You can either do a first chapter and a description of the rest of the book, or a meandering proposal which dips in and out of chapters. You give a list of what

chapters the book will be made up of and what ideas will be in them. You're not forced to adhere to that; things change, chapters come and go, but it proves out of the gate that you've got a whole book's worth of ideas and the ability to write it. Your agent will shop your proposal around to publishers, and hopefully you will eventually get one or more offers from publishers of an advance to write the book.

My writing process is in very discrete stages. I start with the word-generating stage. I go through my text document of ideas, and I pull out the ideas one at a time - all ideas are equal. I'll research the idea and write between 100 and 1000 words on it, save those in their own little text document, write the name of it on a post-it note, stick it on a wall and go onto the next idea. By the end of this, I will have generated tens of thousands of words and have my wall covered in post-it notes. The second phase is chapter-assembly: rearranging those post-it notes into chapters, and actually getting those text documents back up again and trying to mash them all together.

I found writing the second book way easier because I learnt a lot writing the first. Often I didn't know if something was interesting or would work in a book so I wrote it anyway, meaning I hugely overwrote. The first book was 110,000 words and my first draft was 150,000 words. The second time around, I knew I had to overwrite and cut it back, but I had a much better sense going in of what I would actually be able to use. And I cut stuff sooner. I would overwrite earlier on when I was generating content, but I wouldn't put the effort into honing it into book quality before cutting it, so I got more efficient at generating and polishing words.

In terms of level, you don't see some of the best bits of maths until you get to university, so I want to use my writing as a bit of publicity for university-level mathematics, but not in a way that means people can't read it and follow along.

My advice to new authors is: as soon as you've finished your first manuscript, you're half-way there. The other half of the effort is in edits, revisions, changes - and everything takes forever! Part of the benefit of a big publisher is the amount of attention you get from your editor.

Once the book is published, you have to go out and promote it. This means book talks and media, convincing people to read your book. Publishers will first release it as a hardback because they make more money on a hardback, then they release it as a paperback and once again you try to convince people to buy the paperback.

Writing a book dominates your life in a way that other things don't. When I wrote a book about maths mistakes, a huge chunk of everything else I did for five years is also about maths mistakes - live shows, stage shows, YouTube videos, newspaper articles. It's nice if you're totally freelance because the book defines and informs your other work for a period of time. My goal is to write a book once every five years, give or take, since I do a lot of other stuff as well.

Evaluation

I get emails saying thanks and I've read your book, but they make up a trivial percentage of the readership. As a whole, publishing is terrible at data. I could tell you to the nearest view how many views a video has had, but I could not tell you even to the nearest thousand how many readers a book has had. I get six-monthly reports at best, and even then they're fuzzy numbers. You might know how many people bought the book, but you don't know how many people read it or whether they lent it to other people. And some people will borrow it from libraries.

More information

Matt Parker at Penguin Books UK:
www.penguin.co.uk/authors/77633/matt-parker.html

Twitter account: twitter.com/standupmaths

CASE STUDY 15

Mathematical YouTube videos for the standupmaths channel

Organisations involved: YouTube, Stand-up Maths Limited

Case study written by: Matt Parker, Greg Chamberlain, Katie Steckles and Peter Rowlett
(This case study is written based on an interview with Matt Parker for this project; in the text, "I" refers to Matt.)

Intended audience: YouTube viewers with high school level mathematics, including those without prior knowledge; bulk of viewers in the 18-34 age range

Maths content: Various topics

Audience group: Upper secondary or High school, Sixth Form or Junior College, Young Adults, University Students, Adults, Retired

Audience interest level: Receptive, Engaged, Expert

Topics: General maths

Origins of the Project

I've been running my YouTube channel, standupmaths, since around 2009. It's a collection of videos best defined by: things I either thought I would enjoy making, or I would enjoy watching if I was someone else. I have a second channel, where I mess around a lot more, but my main standupmaths channel is for things I enjoy doing which are sufficiently mathematical to justify going on a maths channel.

My goal with the channel (other than entertaining myself) is maths PR - improving the image of maths. It's not so much an educational channel, like Khan Academy or even 3Blue1Brown. Mainly it highlights interesting aspects or components or results in mathematics, in the hope that it will encourage more people to realise they could enjoy mathematics, and be a reaffirming fun experience for people who are already in the nerdy maths-enjoying culture.

Practicalities

The content is aimed at high school level mathematics - any university-level content is not crucial for enjoying the videos. It's a delicate balance between being inclusive of those without prior knowledge, while not boring those who have it.

Each video starts with a good idea - ideas are the fuel that runs everything else. I keep a variety of text documents on my phone; when I see something interesting I'll put it either in the general ideas list, or the Numberphile ideas list (another channel I often make videos for) depending on what style of video I think it would work better for.

When I want to make a video, I look through the lists - or sometimes I'll come across something that inspires me and it'll definitely be my next video. It's called getting nerdsniped - distracted by something that's too interesting to ignore! So you need some way to manage ideas, and you've got that as a pool to draw on.

Maths is rarely topical, so for the most part video ideas are evergreen. I always double check if anyone else has done a good video on the topic in the last 5 years, because I don't want to duplicate or waste effort.

Sometimes I work from a story board, or a list of bullet points, or sometimes just think it through as I go. Personally, I prefer not to make the kind of videos that precisely summarise a topic (not to disparage those who do) - I'd rather try to contribute something, or have a new way to look at it, or add something interesting, so I often make something, or investigate a new bit of maths - pushing the boundaries of what's a sensible amount of effort to put in to something has become my brand.

My videos are often filmed at home with a black backdrop. I started with only kit I had lying around the house - fortunately I've always been into media and film, so I had a camera already, but I've gradually upgraded kit bit by bit. People can start filming on their phone nowadays, and upgrading audio is the next step. I try to embrace success and failures along the way!

I use Keynote for graphics because I was already fluent using it, but you can get way fancier with graphics and filming. Now I work with a couple of different camera people, who come and film me doing things.

I try to do stuff on location occasionally, especially interesting locations - I hired a helicopter one time! I've experimented more with filming myself walking around locations, starting with a GoPro because they're quite cheap; it worked well but I've now upgraded to a DSLR with a gimble that stabilises shots.

You can throw whatever level of effort you want at the video - sometimes I have to think a month ahead with planning, to interview and work with other people. It can be scaled up to full film production, or just with you phone at home and decent quality sound capture and a good idea. There's a low threshold of production quality, but to get above that you need good ideas.

The vast majority of YouTube creators do it as a hobby in their spare time and only have finite resources to throw at it. It does bother a lot of those people when they get negative feedback about accessibility and production quality.

The education YouTube channels, at least the successful ones, are very rarely directly made by educational institutions (though there are exceptions and some are partially funded that way (e.g. University of Nottingham and Brady Haran's Periodic Videos and Sixty Symbols) - so creators have to piece together their own funding. For my videos, the funding is pieced together from some advertising money from Google (probably the smallest source of revenue), some sponsorship for videos and a channel sponsor.

Numberphile is great because it's funded by MSRI for philanthropic reasons. Then there's Crowdfunding (e.g. Patreon), which is a big one for me and it's great because you have a lot of freedom as a creator if you are funded this way. While some YouTubers make money from merchandising, I don't do merch in the traditional sense of mugs and t-shirts with my logo on it.

Getting more followers and views is difficult - once you hit a critical mass, it self-perpetuates, but there are things you can do if you're either starting out or wanting to accelerate your growth. I tweet about my videos, but my YouTube subscribers are five times my Twitter followers. Sometimes it helps to collaborate with other YouTubers with equal or greater audiences.

Occasionally one video will do unusually well and go viral - you get a step function with viral videos, where you'll gain subscribers and return to a higher baseline, so all your new subscribers see all your future videos.

If you're starting a channel from scratch, start making videos on the regular (I started with a video per week for a year) and you find out what you want to do, get over all the early mistakes, you learn what works and what doesn't work; you'll have a very small audience ,and it'll feel like you're putting a lot of effort in for not a huge number of views, but still people will be watching them and you'll be honing your craft.

Once you have that proof of concept, approach another YouTuber for collaboration - even if it's just taking part in a video on their channel, that will drive traffic to your own. On the way up, you should have a trail of that behind you - continue collaborating with smaller channels so everyone gets a chance. It's also good to involve other people in your videos for diversity - I'm a Caucasian middle-aged male face, so any variety beyond that I can get involved the better.

Accessibility

Accessibility is always in my mind, but not necessarily the focus. I did have a good community who subtitled my videos, but Google are turning off that feature and I don't have a plan for that yet. You need to finish the videos early enough to have them subtitled formally before publishing.

The comedic side is a significant part of my videos and I have to be careful because I don't want to exclude people while doing that. I try to put some personality in it - it has to be entertaining so that people want to watch it - but it's important to balance that with making sure there's nothing in there stopping certain people from watching you.

I'm aware of accessibility issues with things like talking too loud, and speed and things - it's interesting; you learn by trial and error. I made a quick video on my second channel where I put a marching band sound in the video - I thought the loudness of it was low enough that you could still follow me talking, but a bunch of people commented saying it was too loud and distracting. I re-uploaded the video with the music loudness reduced.

Evaluation

YouTube lets you see a lot of data about your viewers. For example, 56.3% of standupmaths viewers are not subscribed to the channel (meaning they've found the video from a link or a YouTube recommendation). 3.6% of viewers are younger than 17, and university-age young professionals 18-24 make up 24.6% of viewers. Just over a third are in the 25-34 range. This only includes those signed into YouTube and being tracked, so it wouldn't include, for example, a class of 30 students watching at school.

Anecdotally, a lot of people talk about having watched standupmaths at high school and have memories of that.

Seeing a normal or above-average number of views is a nice metric for either the topic being interesting or the video being shareable - the views figure is a good combination of those two things. Sometimes you put out a perfectly crafted video and it doesn't take off - maybe because it came out at a weird time, or the algorithm didn't recommend it, or the thumbnail wasn't very good.

A lot of it is like reading tea leaves to try and interpret why some videos do well and why some don't. I'm happy with a video that people enjoy watching just from a pure video experience, and they walk away feeling like they have learnt or enjoyed something about mathematics, and I feel I have contributed something unique to that topic.

A video's budget does not necessarily correlate with its success! There's an interesting relationship on YouTube where you don't want to sacrifice authenticity for production values, but people still need to enjoy watching a video and look forward to the next one. My strategy is to have a mix of different types of videos at different production levels, and an overall high level of quality that helps the channel grow and appeal to a wider audience.

More information

standupmaths YouTube channel: youtube.com/standupmaths

CASE STUDY 16

I'm a Mathematician, Get me out of here - Christmas Lectures Zone

Organisations involved: Mangorolla, Royal Institution, Lloyd's Register Foundation, UK Research and Innovation, KPMG, Schlumberger

Case study written by: Shane McCracken and Josie Miller

Intended audience: School students aged 7 to 18

Maths content: Probability, modelling, statistics, algorithms, machine learning; maths and science enrichment; applications of learning outside of the classroom; STEM careers information

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College

Audience interest level: Uninterested, Receptive, Engaged

Topics: Probability, modelling, statistics, algorithms, machine learning, STEM careers

Origins of the Project

The I'm a Mathematician, Get me out of here Christmas Lectures Zone was commissioned by the Royal Institution and produced by the team behind I'm a Scientist with support from Lloyd's Register Foundation, UKRI, KPMG, and Schlumberger.

The aims of I'm a Mathematician are to support students to see STEM subjects as something 'for them' by breaking down barriers around who can study STEM. This is done by connecting students with working mathematicians in live instant messaging-style chats, with opportunities to submit follow-up questions.

The Christmas Lectures Zone offered students a chance to meet scientists and mathematicians whose work linked to the theme of the Royal Institution Christmas Lectures: 'Secrets and lies: The hidden power of maths', and to explore the surrounding mathematic, scientific, societal, and ethical themes.

Practicalities

The Christmas Lectures Zone

The Christmas Lectures Zone ran from 6 to 31 January 2020, and followed the convention of our tried-and-tested I'm a Scientist Zones. Students can take part in live, text-based Chats with mathematicians, submit follow-up questions, and vote for their favourite mathematician.

The Christmas Lectures studio audience were given access to the Zone through question cards distributed during the filming. Questions submitted on these cards were uploaded to the Zone, and accounts created to allow audience members to receive email notifications when their questions were answered (for those who provided email addresses).

Teacher applications for the Zone were opened to all schools in November 2019. Teachers registered on the UK I'm a… activities lists were emailed invites to take part. Promotion was also carried out via Twitter, via the Association for the Teaching of Maths newsletter, and the Ri sent out information through their channels.

Keeping this activity online makes it particularly valuable for rural schools which may not otherwise receive face-to-face science enrichment. Schools who took part were spread across Great Britain, from Fife to Torfaen. Unfortunately not all teachers were given a place; this event was oversubscribed with 71 teachers applying and 57 being offered a place.

There are a lot of benefits to text-only live Chats: Evening the playing field between students and scientists, giving all students an equal voice in the classroom, and creating an environment that is less pressured for students asking questions. This in turn makes the Chats accessible for scientists and students who otherwise would not be comfortable participating in face-to-face engagement, such as SEN and ALN students.

This is reflected in the popularity of the event. In total, we registered 1,156 users, who asked 1,037 questions and wrote 15,866 lines of live Chat.

Evaluation

Generally, there are two main strands to our evaluation for all I'm a… activities:

Formative – We continually review our activities and look for improvements in what we do and how we do it. To this aim we use web metrics, observation of schools during the event, and interviews with scientists and teachers after the activity.

Summative – Using site metrics we can see how students and scientists are interacting: How many questions are asked, how many votes are cast, which are the most active schools and scientists, and other measures.

After each Zone, we collate the data we find in an evaluation report.

Although the quantity of Chats taking place was higher, the quality of the enrichment didn't suffer. One teacher's feedback highlighted the fact that I'm a Mathematician supports students to see mathematicians as 'normal people': "[I'm a Mathematician] was a great opportunity to engage students with maths and give them an insight into where mathematics could take them in the real world beyond school and studies. Our students enjoyed chatting to the mathematicians and it helped them to see that mathematicians aren't just 'professor types' working in universities but mostly they are real people with similar interests to themselves!"

The event also had positive outcomes for the participating scientists and mathematicians. One mathematician fed back in a post-event survey: "Logging in to talk to the classes was incredibly convenient. Often doing outreach takes up half a day or a whole day, where here I managed to easily incorporate a session into the middle of my working day. It made a nice break too."

We hope to run more I'm a Mathematician events in the future.

More information

Website for I'm a Mathematician: imamathematician.uk

Archived Christmas Lectures Zone: secrets.imamathematician.uk

Our evaluation report on the Christmas Lectures Zone: imamathematician.uk/wp-content/uploads/2020/03/2019-CHRISTMAS-LECTURES-Zone-Report-Jan-2020.pdf

CASE STUDY 17

Maths Inspiration shows for schools

Organisations involved: Maths Inspiration

Case study written by: Rob Eastaway

Intended audience: Mainly Year 11/12 teenagers, also Y9/10/13

Maths content: GCSE and A level maths content, real world applications

Audience group: Sixth Form or Junior College, Upper secondary or High school

Audience interest level : Uninterested, Receptive, Engaged

Topics: general maths, mathematical modelling, problem solving, number, applications

Matt Parker presenting a show in Reading

Origins of the Project

Most school subjects have field trips, so why shouldn't maths be the same? That was our original motivation back in 2004. We were also aware that outside London, there was very little in the way of engaging maths lectures aimed at older teenagers, and the quality was patchy. Our aim was to provide large scale, interactive maths shows with a variety of speakers – to ensure that there was 'something for everyone' and to reveal to teenagers that there is far more to maths than just taking exams. The typical size of a Maths Inspiration audience is 500, and over the years we have done shows in over 30 theatres, from Exeter to Canterbury and from Poole to Edinburgh.

Yolanda Ohene presenting a show in Sheffield

Practicalities

Our 'big idea' was to hold shows in regular theatres rather than academic institutions. This was to break away from the idea that maths is only done in schools and universities. Our first show was at the Royal Exchange theatre in Manchester. The speakers were Rob Eastaway, Colin Wright and Helen Joyce (a statistical journalist), and the compere was Claire Ellis, who at the time ran the Enigma project in schools. We promoted that first show by posting flyers to schools and ringing up teachers in the region. Local maths advisors helped to spread the word.

There are significant costs involved in hiring a theatre, managing bookings etc. We decided from the start to charge for seats – partly to cover (some) costs, but also because paying for seats builds commitment, so that schools who book seats turn up. (We'd all had plenty of experience of free "sold out" school events that were half empty.)

We were determined to make the event free for teachers, not least because it is teachers who book the events. We managed to get some sponsorship from PwC to subsidise ticket prices, and in the first year, we charged £5 for student seats.

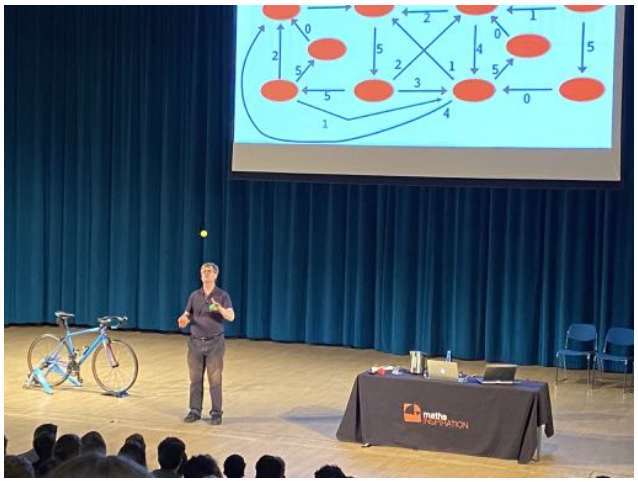
Ticket prices are now typically £10 + VAT, though all teachers and some student seats are free. In March 2022 we offered all schools the first five student seats free.

The scale of bookings requires professional management. We employ two part-time administrators whose role is to manage bookings, sort invoices and finances, and update the database that we keep. Our other staffing is freelance: we have a network of graphic designers, website developers, printers and presentation trainers that we use as

necessary.

We operate on a tight budget, so we don't have a significant funds for marketing. We maintain a database of schools who have attended in the past, and we also promote our shows at teacher conferences and via Twitter and other social media.

Our priority is doing events in theatres. However during COVID we ran numerous live, interactive online shows on Youtube. Online talks open up the opportunity to use a wider range of speakers for shorter slots, and make the events accessible to a wider range of schools regardless of location. We plan to continue to offer occasional live online shows, though these do not have the same impact as experiencing a talk in-person.



Colin Wright speaking at a show in Cambridge

Accessibility

We aim to make our events as accessible as possible. All of our venues are wheelchair accessible, and when schools notify us about audience members with physical impairments, we have always been able to accommodate them (for example, using an on-stage sign language interpreter).

Evaluation

After every show we ask teachers to fill out an evaluation, scoring presenters overall for interest and appropriateness of the content, as well as inviting more general feedback. We've used the same scoring scale since we first ran shows, so we are able to monitor trends in the shows' appeal, and to identify speakers who are deemed to be below par.

We usually rely on teachers to incorporate their students' views in their feedback. We have found that collecting feedback directly from teenagers is time-consuming and the results are rarely insightful. We also have a panel of about ten teachers from around the country who we use for more detailed feedback and insights about the effectiveness of shows.

More information

Maths Inspiration website: MathsInspiration.com

Twitter account: twitter.com/mathsinspiratn

CASE STUDY 18

MathsCity – The home of hands-on maths

Organisations involved: MathsCity, MathsWorldUK

Case study written by: Katie Chicot

Intended audience: Families, schools, the general public

Maths content: Shape and space, problem solving

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school, Sixth Form or Junior College, Families (adults and children), University students, Young adults, Adults, Retired

Audience interest level: Uninterested, Receptive, Engaged

Topics: Hands-on, Shape, Problem Solving

MathsCity website

Origins of the Project

MATHSWORLDUK aims to transform the UK public's perception of mathematics - revealing the engaging, aesthetic and surprising side of maths and empowering people to explore mathematics for themselves.

The core MathsWorldUK objectives are:

To create a world-class visitor attraction in Leeds City Centre (which lacks any STEM visitor centre), that presents maths as playful, exciting, relevant and accessible

To welcome children and families each year from diverse economic, social and cultural backgrounds and inspire them to discover, explore and enjoy mathematical thinking and ideas

To build young people's skills, confidence and interest in mathematics and their desire to learn more – particularly targeting those groups who face the greatest barriers in engaging with maths

To explode negative perceptions of mathematics – among young people and the parents, carers and teachers who influence their career choices – through exciting challenges, surprising applications and inspiring role models

MathsCity is the first step on this journey. The idea of MathsCity emerged in Summer 2020, when it became clear that the Covid-19 pandemic would prevent the proposed UK tour of Explore Maths taking place as planned. As visitor attractions remained closed across the country and Leeds City Council, like all local authorities, rallied to cope with the social and economic impacts of the crisis, this was clearly a very difficult time to be building advocacy, support and funding for a major new capital development.

That said, the need for MathsWorldUK's offer was greater than ever as schoolchildren across the country fell behind in their learning - this was most marked for those in the most economically and socially deprived areas, whose home environments were least suited to home study. It was therefore proposed that MWUK establish an initial physical presence in central Leeds, allowing MWUK to engage with local people and to build brand awareness; to show what it can do and test out ideas and new exhibits with the public; and to start building the track record and evidence base that would be needed in rallying support and funding for the new Mathematics Discovery Centre.

'Ring of Fire' exhibit

Practicalities

Empty retail units were becoming increasingly visible across the city. We approached most landlords in the city centre. Trinity Leeds offered MathsWorldUK a unit next to the popular Trinity Kitchen food court, as an optimal site for MathsCity. This was offered rent free (the rateable value of the unit is £121,000), with MathsWorldUK responsible for bills and business rates.

A member of the explainer team shows a visitor our conic section activity

The exhibits created for the touring exhibition form the core of the exhibition, supplemented with new exhibits linked to geometry, so as to create a stand-alone visitor experience. Most exhibits were bought from Mathematikum and selected by a committee within MathsWorldUK. Designers and museum fit-out companies were commissioned, and staff were recruited (during a recruitment crisis), including a manager and a team of explainers. There was also some legal work that needed to be completed.

Fundraising was a significant part of the work. Access to the discovery centre is by pre-booked tickets, which cost £6.50 for adults and £4.50 for children, plus a booking fee. Tickets can be purchased on the door, but the number of tickets available to purchase in each half-hour time slot is limited, to regulate visitor numbers. We also offer school bookings, and exclusive hire of the venue for larger groups by arrangement.

The designers were briefed to incorporate accessibility into the design of the space, and the whole discovery centre is wheelchair accessible, with ramps to access the upper section. Some but not all of the exhibits are accessible for wheelchair users, and many exhibits are not accessible for blind or partially sighted visitors. We have provided written information cards alongside all exhibits for people to find out more, and explainers are on hand to talk to visitors as needed.

We recruited a freelance marketing company to work for the first three months of MathsCity. Fondant marketing ran a Facebook campaign and contacted local newspapers. School mailouts were paid for and we featured on local radio and television.

Evaluation and feedback

Between 5th October and 28th February MathsCity received 4676 visitors, of which over 500 were school groups. By the end of February half term 2022 we were #72 of 301 'Things to do in Leeds' on TripAdvisor.

For the first three months we have only run light touch evaluation. Less formal initial evaluation with school groups shows an average of 4.2/5 for enjoyment from students. Feedback includes:

'It was more than anything I could've expected! I really enjoyed it!'

'I thought it was going to be boring but it was really fun'

This encapsulates exactly what we are trying to achieve. There are different ways to experience maths and for each person there is a way they can enjoy maths. Full independent evaluation is the next phase of the project.

Feedback we have received in messages and online reviews includes:

"We decided on the spur of the moment to book one last thing during the October half-term and we are so pleased we did. The staff were helpful, friendly and really kind. They took notice of the interests of them both. The children found it easy to talk to any of them and ask any questions they had. We spent over an hour and twenty minutes there and it was talked about all day. Would recommend it to anyone who wants to try something different. Hopefully this can become a bigger space one day!"

"Would highly recommend MathsCity - in particular, it is a great place to visit with people of all different ages. We loved it as adults, but we could see everyone from teenagers to toddlers having a brilliant time. A perfect choice if you have lots of different age groups in your party. We will definitely be returning soon!"

"Wow!! What a place MathsCity is, in Trinity Leeds. We went today and spent 90 minutes doing all sorts of puzzles and learning through play. Our children were in their element 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 grownups too!!"

"We had the most brilliant time – as one girl put it, 'It was amazing, and I've asked my parents to take me back there'. The exhibits at MathsCity are wide-ranging and they are accessible for everyone, irrespective of their mathematical ability."

"The pupils were fully engaged and shared in a brilliant activity: Leonardo's Dome. Set up by the very helpful staff, the pupils very rapidly built up the dome. It was mesmerizing to see it progress and they loved climbing inside it at the end! I thoroughly recommend MathsCity to anyone who likes to solve puzzles and problems, irrespective of their age." - Head of Mathematics at The Grammar School at Leeds

More information

MathsCity website: mathscity.co.uk

CASE STUDY 19

Maths Talks at Science Fiction Conventions

Organisations involved: WorldCon, EasterCon

Case study written by: Nicholas Jackson, Katie Steckles and Peter Rowlett
(This case study is written based on an interview with Nicholas Jackson for this project; in the text, "I" refers to Nicholas.)

Intended audience: Pre-engaged adults and their children at science fiction conventions

Maths content: Various topics including knot theory and codebreaking

Audience group: Adults, Retired, Families (adults and children)

Audience interest level: Engaged, Expert

Topics: General maths

Origins of the Project

I'm based in the maths department at the University of Warwick, where we have some coordinated outreach activities, including Maths Masterclasses and events run by the AMSP. There are also some coordinated outreach events I've been involved with organised by the university's central Public Engagement team. In my spare time, I'm also a STEM Ambassador and helped to run my local Code Club. But one form of engagement I've become involved with is delivering maths talks at science fiction conventions.

This started through my involvement with SF conventions as a hobby - the main one I go to is EasterCon, which happens every year somewhere in the UK, and has been running every year (except 2020) since the late 1940s. I've also occasionally been to WorldCon, which moves around the world. It was in London in 2014, and in Dublin in 2019, but generally it's a bit far away and expensive to get to. A common theme with these conventions is they're volunteer-run and tend to be nonprofit.

Although the audience at these events are primarily science fiction fans, the remit for content is not just SF and fantasy - it also includes stuff that science fiction fans are interested in, which is actually quite a broad range of stuff. They often have talks and panel discussions on relevant science and technology topics, given by people who in their day job have some other expertise or knowledge. For example, I remember a panel I moderated a few years ago on exoplanets, made up of various physicists along with a psychologist - primarily SF fans who were attending the convention anyway - to talk about the psychology of actually maybe going to visit these planets on generation ships. While mostly the guests of honour are writers or artists, at the WorldCon last year, Jocelyn Bell Burnell was the science guest of honour, and she was really interesting.

I did my first maths talk at a science fiction event about ten years ago. I'd never really volunteered to speak before, but I thought 'Maybe I could talk about knot theory?' and I thought there might be five people there. But in a sort of big room, about 40 people turned up to hear me waffle rather incoherently about knot theory. But it was well received, and people throughout the rest of the weekend were bumping into me in the corridor and saying 'I found that really interesting, can I ask you about this bit as well?' - I was pleasantly surprised.

As well as doing my own talks, and occasionally moderating a panel - in the 'tame mathematician' role, with a list of things to address but largely just guiding the conversation in an interesting direction - I've also been involved in organising visits from other speakers about maths.

I was on the programming committee helping with the science programming stream, and during the initial introductory meeting I suddenly thought of Tom Briggs, who's been the educational outreach manager at Bletchley Park, and I said 'Well, if we're looking for invited speakers, my friend Tom goes into schools with an Enigma machine' - and I got about that far, and everyone was nodding. It was tremendously popular - he stayed around after the talk for the rest of the afternoon, outside the room with his Enigma machine, and there was a massive queue for the next three hours. We had to put it in quite a decent size room!

Practicalities

There are different tiers of conventions within the world of SF - the ones I've spoken at tend to be the smaller ones, which are more likely to accept talks like the ones I've done. Around six months before the convention happens, there'll be some topics the programme committee have in mind for panels, and they'll get together and start sketching out an idea, and put out a call for talks and panels.

Almost everyone on the programme is someone who's coming to the convention anyway, so it's effectively a call for volunteers, and they can then choose who would fit on which panel and which talks to put on. Some of the conventions do have funds to pay invited speakers - certainly their travel expenses and accommodation are covered, and a fee if they need one, but this may not be universal.

The talks I've done have usually been about 50 minutes to an hour, with the usual setup - a projector and screen. It's the standard you'd expect from a volunteer-organised convention - they make sure the

venue is accessible with wheelchair access and ramps, and for the larger rooms there's an enthusiastic tech crew with microphones. There's also been a lot of thought and discussion about ensuring diversity in an appropriate way - some conventions aim for as close as possible to 50% gender parity across the programme.

While to convention is attended by a mix of adults and families and has plenty of event provision for children, the subset of that who come to my talks is largely adults (although some people do bring kids along, but they're not expecting the content to be aimed at them). They're on average pretty well-educated, engaged, interested and also quite forgiving. They're a lovely audience to talk to - it's a friendly atmosphere, and there's this general unspoken rule that nothing isn't objectively interesting.

The level tends to range from people who quite liked maths for a while at school, but haven't really done much about it since, up to people who have a PhD in maths, and there will often be people who have master's degres, or PhDs in other subjects. It's quite a broad range and can be a challenge to pitch. I tend to aim for everyone to be able to get something out of the talk - everyone to have understood broadly what I'm talking about on some level, but if I get to a point where I have to say 'This bit is going to get a bit technical, don't worry about it but I'm going to spend a couple of minutes looking at it, but broadly what it means is this', then anyone not following can pick up again later on.

This feels like a big difference from a public talk, or something in a school - I'd probably cut out the more technical stuff. But in this context I'm more confident to push the audience - I've had some great feedback from audience members. You've already cut down from the general public to science-ish people, and then from there to people who within a SF convention, given other options, choose to go to the maths talk.

I went to an event a few years ago where Sydney Padua was speaking - she's an animator and artist who's done books about Lovelace and Babbage, and she talked about how as part of writing that book, she had to figure out what the Analytical Engine would look like. And she really went into the details, and even managed to look at some of the original drawings. About halfway through this talk, she said 'Actually, I don't usually bother with this bit, but on my laptop here I've got some animations of how the gears in the logic bit of the engine worked' - and she got about that far, and everyone in the room was nodding - fascinated. She said 'I can go into a bit more detail about this if you like?' and someone said, 'We are your audience - you are in exactly the right room to give this talk: tell us everything'.

More information

EasterCon Wiki Site: eastercon.fandom.com/wiki/Eastercon_Wiki

WorldCon Website: www.worldcon.org

CASE STUDY 20

Turing Tumble - Programming with Marbles

Organisations involved: Turing Tumble LLC, Sheffield Hallam University

Case study written by: Alyssa J Boswell (Turing Tumble) and Claire Ketnor (SHU)

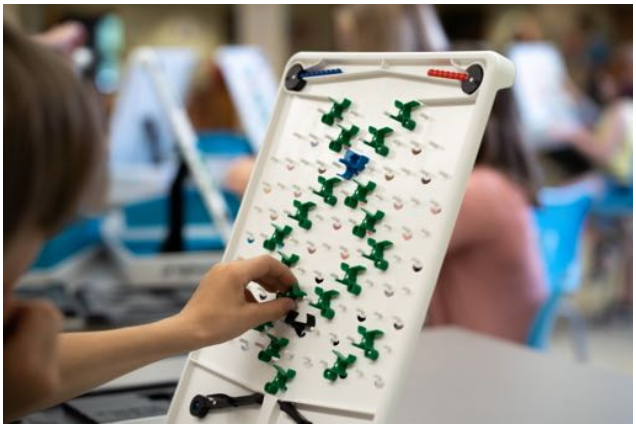
Intended audience: Ages 8+

Maths content: Binary and arithmetic

Audience group: Primary or Elementary, Lower secondary or Middle school, Upper secondary or High school

Audience interest level: Receptive, Engaged

Topics: Number, computer science, hands-on



Origins of the Project

From Turing Tumble:

Turing Tumble was developed by a professor with young kids. He noticed that faculty and students alike treated computers like abstract black boxes and did not have the confidence to write even simple programs that would great improve their ability to analyse data and do their research. He felt that if youth were introduced to how computers work, they would have the confidence to figure out how things work later on. He noticed that there were a lot of toys that claimed to teach kids how to code, but most of them either kept the essence of computing abstract or they made it so that the player would be responsible for knowing if their complicated sequence was right. He wanted to make something that not only was fun and satisfying to play with, but also something that would physically show if you got the solution or not.

The Turing Tumble has 6 different repositionable parts that allow you solve challenges. It has bits and gears/gear bits that show the logic of computers mechanically by switching on and off. When players are setting up the pieces to solve a challenge, they are physically coding without needing to learn any syntax.

SHU workshop:

At Sheffield Hallam University, maths lecturer Claire Ketnor has developed a workshop session, 'Programming with Marbles', which uses Turing Tumble kits.

The session is based around Turing Tumbles. The challenges require setting up the machine to give particular outcomes. The advantages include that each Turing Tumble comes with a booklet of puzzles that range in difficulty, meaning there is always a back-up task for students who are either struggling or find the concepts too easy.

The aims of the session include the development of logical thinking skills and an appreciation of the inner workings of a computer. Another aim is to introduce pupils to binary numbers or to increase their understanding of this topic if they have encountered them before.

Practicalities

From Turing Tumble:

The Turing Tumble is something that is accessible without any extra instruction. The puzzle book starts by introducing one part: the green ramp. The first 4 challenges are designed to give the player comfort with that piece. As they move through the book, more parts are released and the challenges get more and more complex. Each challenge builds on the knowledge that was gained from previous challenges. The challenge are laid out with the starting set-up, the available parts to add with your own creative thought, and the outcome. We recommend the game for ages 8+ because of the reading level, but we've found that younger students enjoy it with a little guidance on where to look for the challenge outcome.

When we've used it in classrooms, we find that the students need very little direction to get started. We usually go over challenge one as a group, highlight that the marbles need to be led down the board with parts (no skipping or jumping), and then the students are ready to go on alone and solve challenge two. Sometimes players need to be encouraged to not have the marble skip down the board, but usually they work that out on their own.

We have a free Educator Guide that has computer logic lessons spread out throughout the challenges. It teaches how Turing Tumble is a mech-

anical computer and how that compares to the electronic computers we are used to. It shows the electronic equivalent of each part and teaches about logic gates, conditional statements and truth tables.

SHU workshop:

The first part of the workshop involves providing an introduction to the Turing Tumble board, the pieces, the general purpose of them and the general format of the puzzles. We then give the pupils chance to have a go at some of the easier puzzles to become familiar with the Turing Tumble. A group of 4-5 pupils would work together around a single Turing Tumble, with staff on hand to answer questions and to challenge the groups.

We would then progress onto introducing or reminding the pupils about binary numbers and their purpose. They are asked to write down the binary numbers for 0 to 15. The 'bit' in the Turing Tumble can either point left or right (which corresponds to 0 or 1 respectively). Having 4 bits above each other allows demonstration of the numbers 0 to 15 and the pupils are asked to work through these by manually changing the bits to represent the different numbers. Following this, the pupils consider a particular exercise in the set of puzzles (challenge 21) which involves setting up the Turing Tumbles to count the number of blue balls (up to 15) that pass through the board. There are also follow on problems (e.g. challenge 22 which involve subtraction and binary numbers) for those who finish quickly.

Throughout the session, activities can be tailored for individual groups. For example, if they are finding the concepts too easy, they can be asked more challenging questions (e.g. about the representation of numbers that are higher than 15) and the puzzles that involve additional thinking. For groups who are struggling, they can be directed to the earlier puzzles within the booklet.

Evidence and Recommendations

During the SHU workshops, evaluation was done by the central team who organised the practicalities of the session. Additionally, throughout the session, staff can evaluate how the session is going. Observing groups allows the person running the session to judge whether the level of difficulty is about right. Ideally the session will stretch the pupils, but will still be achievable. Adjustments can be made easily given the variety of difficulty amongst the puzzles provided with the Turing Tumbles.

More information

Turing Tumble website: turingtumble.com

Turing Tumble Education website: edu.turingtumble.com

Online Turing Tumble emulator: tumble-together.herokuapp.com

YouTube video: Getting Started with Turing Tumble youtu.be/VSVqypPB8S8

YouTube video: How Turing Tumble is a Computer youtu.be/83NYE1Cj9K8

Indices

By audience

adults

families (adults and children)

lower secondary or middle school

primary or elementary

retired

sixth form or junior college

university students

upper secondary or high school

young adults

By audience interest level

engaged

expert

receptive

uninterested

By topic

algorithms

applications

codes and cryptography

computer science

general maths

hands-on

history

machine learning

magic

mathematical modelling

measuring

modelling

number

probability

problem solving

puzzles

shape

statistics

stem careers

Mathematics Engagement Case Studies

Edited by Katie Steckles and Peter Rowlett.

katiesteckles.co.uk/casestudies

Published by
Sheffield Hallam University
Howard Street
Sheffield
S1 1WB

ISBN 978-1-84387-442-3