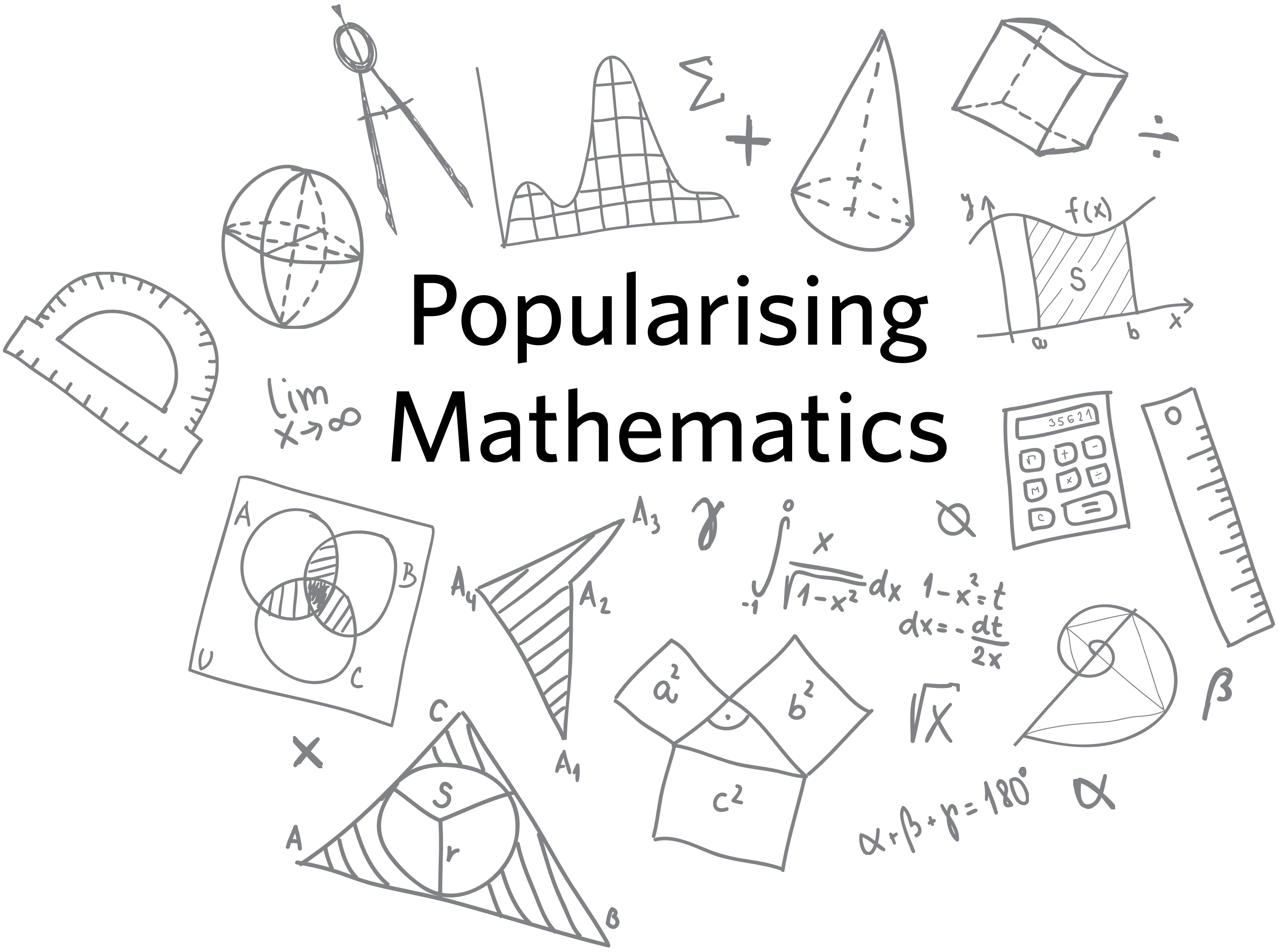

Popularising Mathematics

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Abstract

Mathematics has countless applications in science, engineering and technology, yet school mathematics is one of the most unpopular subjects, perceived as difficult, boring and not useful in life.

'Popularisation' projects can help bridge this gap, by showing how exciting, applicable and beautiful mathematics is. Some popularisation projects focus on telling the wider public *about* mathematics, including its history, philosophy and applications; other projects encourage you to actively *do* mathematics and discover surprising relationships and beautiful results using mathematical reasoning and thinking.

In this report I will develop a framework to classify and evaluate popularisation, and analyse a wide range of existing projects – ranging from competitions to websites, movies, exhibitions, books and workshops. I also reflect upon my personal experiences in designing popularisation activities.

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Introduction

Mathematics is both difficult and abstract [1]. This makes it much less accessible to the general public, and throughout history many mathematicians have taken pride in its exclusivity and apparent lack of useful applications.

But at the same time there have been many efforts to 'popularise mathematics', trying to make it accessible and enjoyable. From 1704 to 1841, the Company of Stationers published *The Ladies' Diary*, including mathematical puzzles *"designed for the use and diversion of the fair sex".* Lewis Carroll (alias Charles Dodgson, 1832 – 1898) studied mathematics and wrote several recreational mathematics books – such as the *Pillow Problems*, to be *"worked out in bed at night without pencil or paper"*. Mathematician David Hilbert (1862 – 1943) gave a famous series of popular lectures, and in 1956 Martin Gardner (1914 – 2010) started writing a recreational mathematics column for *Scientific American*. Until 1981 he wrote about countless mathematical games, ideas, puzzles and stories; he was succeeded by Douglas Hofstadter, Ian Stewart and, most recently, Dennis Shasha. [17]

In recent years there has been an explosion of similar mathematics education projects – whether called 'popularisation', 'outreach' or 'enrichment'. Maybe this is because students, teachers and mathematicians have become increasingly unhappy with the way mathematics is taught at school – or because politicians understand the importance of mathematics in our digital world, and the importance of technical jobs for the economy.

[1] "Abstract" in the sense of decontextualisation as well as the emerging of mathematical meaning and ideas [1].

Part 1: A Framework for Mathematics Popularisation

1.1 The Value of Mathematics

Mathematics is of fundamental importance in just about every aspect of life: public transport and aircraft networks, computers and the internet, delivery chains for supermarkets, structural engineering, digital music, and so much more. Without mathematics our civilisation would be little more advanced than the ancient Egyptians – and even they used numbers to calculate taxes, distribute land and construct the pyramids. To continue scientific and technological progress, we have to continue teaching and studying mathematics.

The Practical Value of Mathematics

Many of today's most important and most innovative jobs involve a significant amount of mathematics – from engineering to software development, scientific research and finance. These disciplines are essential to ensure technological and scientific progress, as well as economic growth, and they can only thrive if we encourage more students to study mathematical or scientific subjects.

But mathematics is also useful in "everyday life" – whether you are measuring time and distances, comparing sale offers or doing personal finance. Managers and politicians must be able to interpret statistical data and understand environmental reports or productivity assessments written by mathematicians. Basic numeracy is required for almost all jobs, and having an A-level in mathematics increases the expected salary, on average, by 10% [2].

The Intrinsic Value of Mathematics

But we don't just study mathematics because of its practical applications. To solve a mathematical problem, you need a variety of different skills: hypothesising, structured thinking and logical reasoning, finding patterns, testing particular examples, generalising, abstracting, representing information, and many more.

These skills are useful in many parts of life which are not related to mathematics. *"Mathematical thinking"* as an intrinsic skill is just as important as the content and theorems you learn when studying mathematics.

The Cultural Value of Mathematics

Mathematics is the language in which the laws of nature are written. It is one of humanities most noble endeavours to understand the universe we live in, and that would not be possible without mathematics.

In recent years, mathematics has also become the language of technology, particularly of computers. Learning mathematics is fundamental for understanding these applications which have become so important in our life.

Mathematics is also the one truly international – and, in fact, intergalactic – language. Mathematics truly spans borders and allows for a great amount of collaboration – and maybe also cultural understanding and peace. Or, in the words of G H Hardy [3],

> *"The applications of science have made, on the whole, at least as much for evil as for good. Mathematicians like Gauss are justified in rejoicing that there is one science whose very remoteness from ordinary human activities should keep it gentle and clean."*

The Joy and Beauty of Mathematics

Finally it is important to remember that for many mathematicians, the driving motivation is the joy and excitement of solving problems, and the pleasure of discovering beautiful patterns and underlying structures – very much like music or art.

Conversely, music can be analysed using mathematical concepts like symmetry and group theory, at a much deeper level than the mathematical equations for sound waves, and similar ideas apply to art.

Mathematics is also linked to philosophy and fundamental questions about truth, knowledge and logic.

1.2 Defining Mathematics Popularisation

The Need for Popularisation

Mathematics is one of the most unpopular subjects at school – many perceive it as boring and irrelevant [4] while it attracts deep hostility and hatred from others.

More importantly, *"the popularity of mathematics diminishes during the time students are exposed to mathematics at school"* [5] and mathematicians are perceived as *"arrogant, elitist and eccentric male social misfits"*. Even adults are often proud to have been 'bad at maths' [12].

This is very concerning – particularly when considering the great importance of mathematics. Popularisation can try to change these misconceptions, by making the subject more exciting, fun and creative, and by connecting it to its countless applications.

Reasons for the negative image of mathematics might include the fact that it can be very difficult, and that everything new builds upon things learned previously – not understanding one topic may make it very hard to keep up in the future.

According to M L Sturgeon [cited in 5], another problems is the lack of public recognition of mathematical success in the form of wealth, acclaim or medals, while *"to much worth-weight is given by our culture to superficial high profile activity"*.

Furthermore, the kind of mathematics taught in schools is only a small and biased selection of what mathematics is *really* about. It focuses on memorising procedures rather than exploring and discovering, on dry algebra and arithmetic rather than exciting real-life applications. The aim is for students to solve exam questions most efficiently, rather than gaining a deep understanding of mathematics [13].

In [14], Paul Lockhart compares this to music students learning to read and transpose notes without ever hearing or playing any music, or artists learning about colours, brushes and painting-by-numbers without ever creating anything new.

Defining Popularisation

It is hard to define exactly what we mean by "popularisation" – or rather, to find a more appropriate name for it. While 'popular mathematics' is often associated with *recreational mathematics*, rather than more serious mathematics such as mathematics olympiads, 'outreach' is used primarily for work done by universities and museums, and 'enrichment' usually refers to activities extending or enhancing classroom teaching.

In [5], Howson and Kahane describe popularisation as *"any effort to bridge the gap between science and public understanding of science"*, which consists of *"sharing mathematics with a wider public"* as well as *"encouraging people to be more active mathematically"*.

Correll [cited in 15] defines enrichment as *"any experience that replaces, supplements, or extends instruction beyond that normally offered by the school"*. In [16], Wai Yi Feng creates a framework for classifying mathematics enrichment, and distinguishes between four different categories:

- Development of exceptional mathematical talent,
- Popular contextualisation of mathematics,
- Enhancement of mathematics learning process,
- Outreach to the mathematically underprivileged.

These categories are only broad guidelines and in practice you often find that a project corresponds to more than one category.

In [17], Schneider remarks that *"the primary attraction [of popularisation] may not be mathematics, but rather something else such as music, humour, or physical activity. Without willing participants, without an audience, there is no possibility of success, no matter how worthwhile the mathematics"*.

One of the key characteristics of popularisation is that it is not bound by a curriculum or assessment. Activities are provided *"in freedom, not by compulsion"* and don't *"imply work and hard effort, but freedom and pleasure"* [5]. For example, students could be able to investigate topics and problem, with neither student nor the teacher knowing where the explorations might lead.

'Popularisation', as used in this report, includes all the aspects above: from inspiring children, to making mathematics accessible to a wider audience, to supporting particularly talented children. The 'wider audience' can include children, adults, professionals as well as researchers working in different areas of mathematics. Content of popularisation can include mathematical theorems as well as history, applications, problems and recent developments.

Two Approaches to Popularisation

There are two distinct approaches to mathematics popularisation, each targeting one of the shortcomings of school mathematics:

- **Learning *about* mathematics**
  School mathematics gives very little insight regarding what mathematics is used for in real life: that prime numbers are used when sending secure emails, that trigonometry is used when using GPS devices, that differential equations are used when sending rockets to the moon. Popularisation projects can help shift the perception of mathematics from 'boring and useless' to 'fun, useful and exciting'.

- **Learning *to do* mathematics**
  School mathematics is very computation focussed: children are taught procedures and algorithms to solve a particular problems, and have to use them in a variety of different cases. Children are rarely asked to come up with these procedures on their own – to solve a completely unknown problem. This removes any exploring, creativity and investigating which should be a key part of learning mathematics. Popularisation projects can make mathematics more engaging as well as teaching reasoning and mathematical thinking.

Note that one of the reasons why these aspects are difficult to do at school is the lack of possible assessment – this will be discussed further below.

There has been considerable debate regarding whether the audience has to be 'mentally active' – directly involved in 'mathematical thinking' – for popularisation (or education in general) to be most effective.

Many outreach projects [8, 18] want to actively engage their audience in mathematical thinking. On the other hand, some of the most interesting applications of mathematics are based on concepts beyond the understanding of a lay audience. Popularisation should also target those who are *"too weak or too lazy"* [5] to actively think about mathematical problems.

Clearly there is a much larger audience in the latter case, without any barriers to entry both in terms of ability and willingness. One has to find a balance between making mathematics accessible to *all*, and making mathematics *active*, *free* and *creative*.

Target Audiences

Mathematics popularisation, in different forms, can be targeted at every part of the population. The following follows a distinction similar to [5]:

- **Children:** ***Older children who enjoy mathematics***
  Students who enjoy mathematics, or are sufficiently talented, will benefit from learning more about the history and range of applications of mathematics – especially when linked to career opportunities in mathematics, science, engineering, finance, or related subjects.
  In addition, we want to give students the opportunity to solve difficult mathematical problems, and engage in more advanced mathematical thinking. This can't easily be done at school because it would exclude many other students.

- **Children:** ***Older children who don't like mathematics***
  Popularisation can also convince those students who think mathematics is boring, of its importance in life, and inform them about the number of jobs which require mathematical skills. Showing weaker students that mathematics not just about algebra and arithmetic might also increase their self-confidence.
  According to [5], fear of mathematics *"will have built up over many years of conventional schooling"*, and thus needs *"something unconventional […] outside the classroom"* to be changed.

- **Children:** ***Younger children who are indifferent or have yet to decide***
  A misguided perception of mathematics might be avoided if popularisation was targeted at all students from the beginning of their schooling. This could take the form of mathematical games and visual puzzles, countless of which can be found, for example, on the *Nrich* website [18].
  No primary school child dislikes mathematics, yet, and below I will discuss how popularisation can be incorporated in the school curriculum.

- **Adults:** ***Parents and the general public***
  Adults might be interested in mathematics as general knowledge, including applications, historical, cultural and philosophical aspects, because they recognise its value but didn't understand mathematics at school, or because they would like to talk about mathematics with their children and grandchildren.

- **Adults:** ***Professionals, teachers and mathematicians***
  Popularisation can also target other mathematicians or other adults working in mathematics related professions. While the audience has a solid mathematical background, they might not be familiar with a particular area of mathematics. The objective is not to make mathematics more popular, but to promote collaboration and increase general/subject knowledge.

A Framework for Mathematics Popularisation

If we combine the distinctions in the two previous sections, we get a table showing where and how mathematics popularisation can take place. The result is similar to the grid by Henry Pollak described in [5]. In practice, these distinctions are more fluid and often overlap.

	Learning *about* Mathematics	**Learning *to do* Mathematics**
Children *Older children who enjoy mathematics*	• Learn about mathematics related career opportunities • Learn about history, evolution and applications of maths	• Develop mathematical talent • Prepare for mathematics courses at university • Provide fulfilment
	Summer schools and gifted programmes, competitions, extracurricular activities, books, magazines, websites	
Children *Older children who don't like mathematics*	• Convince students of the importance of learning maths	• Develop life skills such as reasoning or data analysis • Increase self-confidence
	During lessons, field trips to museums, visits by experts	
Children *Younger children who are indifferent or have yet to decide*	Show that maths can be fun and exciting	Develop logical thinking and problem solving skills
	During lessons, roadshows, field trips to museums, games	
Adults *Parents and the general public*	• Raise awareness of mathematics • Show why mathematics is useful and important	
	Books and magazines, TV and movies, exhibitions, public lectures	
Adults *Teachers and mathematicians*	• Provide insight into new areas or applications of maths	
	Lectures and conferences, books, magazines	

Notice that two of the 'learning to do'-cells are empty. Projects in these categories could include professional development, higher education or online courses. While certainly important to spread mathematical knowledge, these forms of education have very different characteristics, particularly due to their formal structure, and will not be discussed during this essay.

1.3 Designing Mathematics Popularisation

Topics and Content

Almost every area of mathematics can be 'popularised' in some way and to some extent – this is shown in countless books by authors like Ian Stewart, Marcus du Sautoy or Keith Devlin. Particularly interesting or fun topics include cryptography, fractals, origami, gambling and card tricks, and dynamical systems like population dynamics or catastrophe theory.

Mathematics is so diverse and varied that it is possible to find enjoyable or interesting topics for anyone, even if they dislike other parts of mathematics.

Topics are particularly suitable for popularisation if they have some of the following characteristics:

- **Relevance**
  The topic is relevant to the audiences' life, either directly (e.g. interest rates or percentages) or indirectly (e.g. used to make technology which the audience uses). The relevance may be fictional (e.g. in Ian Stewart's *"The Science of Diskworld"* or Simon Singh's *"The Simpsons and their Mathematical Secrets"*). For a professional audience, the topic may relate to their own work.

- **Adaptability**
  Some topics are particularly suitable to illustrate general mathematical ideas and methods for problem solving, such as algorithms, generalisations, proof techniques or approximations. These ideas can be applied in many other situations and problems the audience might encounter.

- **Culture**
  The topic links to issues in the history and evolution of mathematics, relates to recent developments and unsolved problems, or helps the audience understand mathematicians and professionals who use the topic in their everyday work.

- **Sensation**
  The topic is fun or surprising, or it showcases the beauty, generality or effectiveness of mathematics – causing *"positive emotional attitudes towards mathematics"* [5].

It is interesting to compare these characteristics with the four parts of the first section on the values of mathematics…

Most popularisation projects don't want to *"provide complete information on any subject"* [5]. Topics are reduced to their key concepts and insights, showing why they are useful and beautiful, and inviting the (interested) audience to investigate further.

While it is acceptable to simplify and reduce concepts as far as necessary, they should still be true – in the sense that you don't have to *unlearn* anything at a later stage.

There can also be a danger in oversimplification, because it is often the complexity of mathematics which is beautiful and most insightful.

Link to School Mathematics

In the previous section, popularisation has been described as *"complementary to"* or even *"a correction for"* school mathematics [5]. The latter aspect certainly should not be the case, and instead one should think about how certain aspects of popularisation could be incorporated into the school curriculum.

One of the characteristics of popularisation is that it is free from constraints, allowing for exploration and investigation. This is difficult at school, where teachers have to follow a structured curriculum with fixed attainment targets.

While teachers could easily talk about history or applications of mathematics, it is much harder to engage students in mathematical thinking. While *'free'*, this still requires significant teacher involvement: to recognise mistakes or nudge students in other directions. Since all students will think about something slightly different, this can be an impossible task for one teacher in a class of 30.

Another problem is assessment: unconstrained mathematical reasoning and investigating can't be marked using a uniform and fair system.

But there are many other ways in which popularisation finds its way into the classroom – from video recordings of popular lectures to school visits to museums and exhibitions [17]. Preparation for competitions like the *UK Mathematics Challenges* is often done at school, and teachers – particularly in primary school – use games to make their lessons more engaging.

Cooperation and Collaboration

To reach a wide audience, it is necessary for mathematicians and teachers to work with journalists, publishers, producers, and many others. The latter groups usually don't have a mathematical background, so it may first be necessary to promote mathematics among your collaborators [7]. This can often be a trial before targeting a wider audience.

It is also important for those working in mathematics popularisation to collaborate and exchange information on successful projects and best practices.

There are countless science museums and science centres around the world. Unfortunately the mathematics underlying scientific achievements is often lost, in favour of visually impressive experiments. Maybe this is something that can be changed in the future.

One way of making mathematics look more engaging and fun is to integrate it with popular culture. This was shown in the TV series *Square One TV*, which produced maths music videos with celebrity singers as well as video game parodies [17]. Of course there will be significant differences depending on the target age group and target culture/country.

Issues regarding Genders and Minorities

In public perception – and, sadly, real life – mathematicians are mostly male [19]. There are a number of mathematics popularisation projects targeted exclusively at girls, and even more for computer science. Examples include the *Girls Rock Maths* summer camps in the US [20] or the *European Girls' Mathematical Olympiad* [21].

It is important to encourage more girls to study mathematics, but – personally – I think this can best be achieved by showing that mathematics is universal and that girls can be just as mathematically talented as boys – rather than by giving them special treatment.

A great way to target certain minorities or different cultures is through the history of mathematics: ancient Chinese, Indian, native American or medieval Arabic mathematics. While culturally and mathematically relevant, these topics are usually simple enough to be taught at primary or secondary level. Examples could include Chinese magic squares or the Nazca lines in Peru.

1.4 Evaluation of Popularisation Projects

According to Howson and Kahne [5], *"a bad image of mathematics may result in an enormous national loss in the future [while] a good or improved image may prove immensely beneficial to any nation in the world"*.

Unfortunately it is very difficult to measure this national loss or gain. According to Lynn Steen [10], *"the purpose of popularisation is to raise awareness, not to educate, and the criterion of success is not an increase of knowledge, but a change in attitudes"* – and attitudes are hard to quantify.

Furthermore, the true benefit of mathematics popularisation often lies many years in the future, e.g. when former students apply to university, make career choices, or talk to their children.

Finally, all popularisation projects have slightly different audiences and objectives, thus making them very hard to compare.

In order to make a case for mathematics popularisation, or to improve existing projects, it is important to evaluate their impact. Possible research questions can fall into two categories:

- **Success of Popularisation Project**
  Was the project 'useful' in that it improved the mathematical understanding of children or got more children and adults interested in mathematics? This may be more about the pedagogical principles underlying a certain approach to popularisation, rather than a particular project.

- **Quality of Popularisation Project**
  Was the project designed in a way that is accessible to all *targeted children, presented in a professional and appropriate manner, using the right tools and technologies? Did children or adults enjoy participating and did they engage with the topics?*

Note that while the *quality* will clearly have some effect on the *success*, it may not be possible to determine the extent of this relation.

Some might argue that the *success* is the only important aspect when evaluating projects, but it is hard to measure due to the problems outlined above: observing changes in attitude rather than ability, a delayed observable response, and the difficulty of comparing different projects.

The *quality*, on the other hand, can be determined immediately after a project, by observing it and interviewing the participants. The questions and criteria might vary depending on the audience and the medium (live, TV, internet), but there has been much research targeting particular popularisation projects.

Examples of Research Projects

In 2004, Back et al. [22] asked 70 students aged 10 or 11 to solve a 'non-standard mathematical problem' from the Nrich website [18] and then complete a questionnaire. While not providing details regarding the questions or background of students, the questionnaire answers were very polarising:

- Some students *"appreciated the chance to work on something different and challenging"*. The responses show that their were motivated, *"saw the potential for learning […] and gaining new insights"* and *"recognised the value of the resources available"*.
- The responses of other students suggest that they did not enjoy working on a problem, which turned out to be impossible, nor did they *"recognise that there was anything to be gained"*. It is interesting to note that these students *"focussed on the arithmetic rather than stepping back and considering the underlying structure of the problem"*.

A similar study was conducted by Esty and Schneider [7] regarding the American *Square One TV* series. Children were interviewed individually for 55 minutes and had to solve non-standard mathematical problems. A similar interview was repeated at the end of the experiment, during which one group watched 30 half-hour episodes of Square One TV while a second control group did not.

Solutions were graded according to *"the number and variety of problem-solving actions and heuristics used"* and *"the mathematical completeness and sophistication of their solution"*. The gains were *"significantly greater for the experimental group […, while] neither score […] interacted with gender or socioeconomic status"*. [7]

A large-scale research project was commissioned by the Royal Institution regarding their mathematics masterclasses [23]. Researchers interviewed students, presenters, teachers and organisers, and asked a total of 971 students to complete a questionnaire:

- 64% of the students (strongly) agreed that their attitude towards mathematics had improved;
- 70% of the students felt that their ability in mathematics had improved due to the masterclasses;
- 59% of the students agreed that the masterclasses had encouraged them to study maths in the future.

Note, however, that students' perception does not necessarily reflect reality – in fact it is unlikely that 13 and 14 year olds can accurately judge their progress over the course of a year, or predict whether they will study maths in the future. More useful for improving the masterclasses were comments like *"shorter sessions"*, *"more or longer breaks"* or *"more activities in the sessions"*.

Part 2: Case Studies of Popularisation Projects

The aim of this part is not to analyse any popularisation project in detail, but to give an overview of their breadth and variety, and to compare the advantages and disadvantages of the various media.

2.1 Mathematics Competitions

Competitions are a fantastic way to get students to *do* real mathematics: trying to solve unknown and often very difficult problems without external help.

On the other hand you might say that many competitions, such as the IMO, are *"preaching to the converted"* [5] in the sense that they target students who already enjoy mathematics and are very good at it. However *popularisation*, as defined in the previous part, includes *'developing mathematical talent'* and *'providing fulfilment'* for talented students.

IMO and National Olympiads

The International Mathematical Olympiad is targeted at pre-university students and has been taking place annually since 1959. Since then, 121 countries have participated with teams of up to 6 students. [24]

Each IMO consists of six difficult problems from areas like geometry, number theory, functional equations and combinatorics which are not usually taught at school. Three problems each are solved in 4.5 hour sessions on two consecutive days. [24]

Preceding the international competition, there are many smaller, national competitions or camps to select every country's team. In the UK, this is the *Senior Mathematical Challenge* (see below), then two rounds of the *British Mathematical Olympiad*, and finally two training and selection camps at Trinity College Cambridge and Oundle School [25].

Mathematics Olympiads target students who are especially talented at mathematics, and participants are likely to also enjoy mathematics. While it is important to *'develop mathematical talent'* and *'provide fulfilment'*, there is a danger that slightly weaker students – who would still do very well in mathematics or science courses at university – are deterred by the competitive nature, great difficulty, and by the very biased selection of questions, focusing exclusively on certain parts of pure mathematics.

Because of its size and reputation, the IMO generates much publicity and news stories targeted at the general public. There have been two major TV documentaries about the IMO: a US documentary in 2006 and a BBC UK documentary in 2007, *'Beautiful Young Minds'*, which was nominated for a BAFTA as well as other awards. [26]

As an example, here is Problem 2 from the IMO 2012 [24]:

> Let $n \geq 3$ be an integer, and let $a_2, a_3, \ldots, a_n$ be positive real numbers such that $a_2 a_3 \ldots a_n = 1$. Prove that $(1 + a_2)^2 (1 + a_3)^3 \ldots (1 + a_n)^n > n^n$.

AMC, Kangaroo and UK Mathematics Challenge and

The *Australian Mathematics Competition* (AMC) has been taking place since 1976, with more than 600,000 participants [27] from 80% of all Australian high schools [5]. There are several different papers for different age groups.

All questions are multiple choice with five possible answers. Questions are in increasing order of difficulty, with later questions being worth more marks. Marks will be deducted for incorrect answers, so that, on average, a random selection of answers will gain 0 marks.

Questions are considerably shorter than Olympiad questions. The multiple choice format and the fact that only the final answer is judged, not the method or reasoning, means that a possible – and often very successful – method is to eliminate wrong answers or guess one of the two "most likely" answers. On the other hand, the answers are often designed to mislead participants…

The fact that there are few prerequisites and easy questions at the beginning makes this competition accessible to weaker students. The puzzle nature of the problems allows *all* students to have fun doing mathematics. The AMC combines *'learning to do mathematics'* for all three groups of children in the framework in part 1, and this may be one reason for its success.

Many similar competitions have been held elsewhere. The *Mathematical Kangaroo* in the EU is with 5,000,000 participants from 47 countries the largest mathematical competition in the world [28]. The *Mathematics Challenge* is organised by the *UK Mathematics Trust* (UKMT). In 2007 there were 87,400 entries to the *Senior Maths Challenge* [29], which also forms part of the selection process for the UK team at the International Mathematical Olympiad.

This question is one of the hardest ones in the 2007 UK Senior Mathematical Challenge [29]:

> A bracelet is to be made by threading four identical red beads and four identical yellow beads onto a hoop. How many different bracelets can be made?
>
> **A** 4 **B** 8 **C** 12 **D** 18 **E** 24

Maths Team Challenge

This competition is also organised by the *UK Mathematics Trust* and consists of regional rounds and a national final for teams of four sixth form students from different schools.

In a *group competition*, all four students have to solve 10 questions in a short amount of time – thus having to distribute them efficiently and allocate their resources. Then all teams are split up into two pairs. Without the pairs talking to each other, the teams first have to solve a crossword, in which one pair gets the horizontal clues and one pair gets the vertical clues, and finally a relay race, where the solution to one question of the first pair is required to solve the next question of the other pair. [30]

There are very few mathematical team competitions – mainly because solving a mathematical problem is a very isolated process. This competition, on the other hand, makes problem solving much more fun and engaging – as well as greatly improving teamwork skills. This is particularly important since scientific research in real life is usually a collaborative effort!

Other Competitions

There are many, *many* other mathematical competitions, at local, national and international level. A selection can be found on *en.wikipedia.org/wiki/List_of_mathematics_competitions*.

2.2 Masterclasses, Workshops and Summer Schools

Like the competitions above, almost all masterclasses and summer schools are targeted at students who enjoy maths or are most talented. Investigating mathematical problems and attending “lectures” can give participants a taste of what university courses and research in mathematics are like, and what possible career choices there are.

Unlike competitions, students are taught directly rather than having to prepare on their own or with their teachers. Workshops can also cover a much wider range of topics, including various applications of mathematics. They can include *learning about* and *learning to do* mathematics.

RI Mathematics Masterclasses

The Royal Institution was founded in 1799 in London, and is famous for its annual Christmas Lectures. (These lectures would also fall into this section, but are very rarely on mathematical topics.)

Since 1978, the Royal Institution also organises regional Mathematics Masterclasses throughout the UK. Gifted year 9 students from local schools – as recommended by their teachers – attend a series of six to ten 2.5 hour classes on Saturday mornings. Most classes consist of varied formal teaching as well as individual and group tasks. Students learn *about mathematics* as well as *to do mathematics*. [31]

Classes are given by different speakers – mathematicians, teachers and professionals from industry – and cover a large number of interesting topics such as cryptography, graph theory, game theory, number theory, or art. Written summaries of previous masterclasses have been published by Michael Sewell [32] and C J Budd and C J Sangwin [33].

The RI masterclasses are a fantastic way to get students interested in and excited about mathematics – and, at that scale, probably the very best kind of popularisation possible. They do, however, require some effort from participating students and parents, since they take place on Saturdays and students have to participate in an entire *series* of classes. In addition to the selection at schools, this might be a barrier to entry for some.

Another problem is that with 30 to 60 students from different schools per class, significant differences in ability are inevitable. Masterclass topics are rarely related to the curriculum, and presentations on applications or history of mathematics will be interesting to all, but some students might find the activities much more difficult than others.

The RI's guidelines for speakers [31] list the following points to consider when designing a masterclass:

- *What is the **story** of the topic?*
- *Where do students need to **start** and what do they **need to know by the end**?*
- *What **problems / activities** could you get them to work on during workshops?*
- *Are there any **unusual or exciting** links to the topic or ways of presenting the topic?*
- *Can you think of some good **pictures or videos** linked to the idea?*
- *What is your **"Big Finish"** – the WOW moment at the end, or something which brings the whole class together?*

These guidelines will be useful for almost any kind of mathematics popularisation.

Others

The Royal Institution also organises one week summer schools which usually focus on students' investigating rather than mathematical lectures.

In Ireland, the *Mathematics Applications Consortium for Science and Industry* (MACSI) organises a residential summer school since 2007. It focusses on real life maths problems like food transportation and management, automotive design, internet, banking, mobile phones, or special effects [12].

There are countless other maths summer schools, particularly in the US, targeting various groups of students and often focussing on a particular subject. Examples can be found at *www.ams.org/programs/students/high-school/emp-mathcamps*.

2.3 Mathematics on TV and in Movies

Mathematics is a difficult subject to present on screen, because equations and proofs rarely give exciting imagery – particularly when compared to exploding chemicals or mysterious galaxies.

One approach is to focus on certain applications of mathematics, such as crime prevention in *NUMB3RS*. Another approach is to focus on *mathematicians*, both real and fictional. This has been done in BBC Horizon's *'Fermat's Last Theorem'* about Andrew Wiles' journey to find a proof.

Unfortunately, a common trope is the *'Mad Mathematician'* who is a genius but is eccentric and unsociable or even insane (John Nash in *A Beautiful Mind*, Moriarty in *Sherlock Holmes*, everyone in *Proof*, Doctor Who) [34].

Even worse are high school movies in which the hero (often female) dislikes mathematics (Bella in *Twilight*, Mia in *The Princess Diaries*) or where mathematics is shown as intrinsically *'nerdy'* (*Malcom in the Middle*, *Mean Girls*) [35].

Square One TV

Square One TV was a 30 minute TV series broadcasted daily in the US from 1987 until 1994, and targeted at 8 to 12 year old children. Every episode consisted of several segments, such as *"humorous parodies"* of musicals, game shows or commercials [17]. The three main goals of *Square One TV* were [17]

- to ***"support and stimulate interest in mathematics"***, by showing how *"powerful and widely applicable"* it is, how beautiful, and that it *"can be understood and used by non-specialist"*,
- to ***"model good problem solving behaviour"***, as shown by the *"series' characters' encounters with mathematical problems"*,
- and to ***"present a broad view of mathematics"***, particularly when compared to school mathematics which is *"concentrated on computational arithmetic"*.

One particular difficulty was the *"highly competitive environment"* [7] of television, where children can simply change the channel if they don't enjoy a program. In particular, mathematicians' *"natural interest in and enthusiasm for mathematics is, in fact, unnatural"*. A broad audience must be attracted in other ways – in *Square One TV* this was successfully done using humour and parody.

Detailed research was conducted to determine Square One TV's success in achieving goals 1 and 2 above [7, 17].

NUMB3RS

Unlike *Square One TV*, the main objective of the award winning US television series *NUMB3RS* is entertainment rather than education. A genius mathematician, Charlie Eppes, uses mathematics to help the FBI solve crimes. Topics range from cryptography to game theory, calculus or chaos.

The popularity of the show – with around 10 million viewers per season [36] – is a fantastic platform to showcase the wide range of applications of mathematics. Interested viewers can read a variety of companion books and websites to learn more about the mathematical concepts in each episode.

Many mathematicians were consulted when writing the episodes. However mathematical concepts were often used out of context, simply to add 'mathematical sounding jargon' – mathematical accuracy and *"getting it to fit with the plot [was] no priority of the NUMB3RS team"* [37]. Viewers will get a sense of the importance of applications of mathematics, but they won't *learn mathematics* or see how it is *actually* used. Prime time television may simply not be the right place to do that…

Mathematical Movies

There are no feature length movies *about* mathematics, as there are nature or science documentaries, but there have been a number of movies with significant mathematical content:

- **A Beautiful Mind** (2001, 4 Academy Awards) is a biography of the mathematician John Nash and the only major movie portraying a real mathematician. It introduces some ideas in game theory and cryptography.
- **Good Will Hunting** (1997, 2 Academy Awards) is about a young genius who works as janitor at MIT, where he is discovered by a mathematics professor.
- **Proof** (2005) portrays a young and female mathematician who struggles with her fathers' mental illness and her own instability, while being constantly underestimated.
- **21** (2008) is about a team of MIT students using mathematical skills to count cards in Las Vegas. The movie mentions the Monty Hall paradox as well as the Newton-Raphson approximation.
- **Travelling Salesman** (2012) is mathematically and philosophically ambitious, discussing the possible consequences of a proof of the P vs PN conjecture.

More mathematicians and mathematical references appear in *Jurassic Park* (*"You've heard of non-linear equations? Strange Attractors?"*), *Die Hard 3* (*"… a 5 gallon and a 3 gallon jug. Fill one jug with exactly 4 gallons of water."*), *Enigma*, *Fermat's Room*, *Agora* and many other movies in [38] and [39].

Many of these movies have a *"Genius Bonus"* [40]: they are fun to watch for anybody, but are even better if you understand the hidden references, such as the meaning of equations on a blackboard…

Popular Science Television

Many popular science TV series have a few episodes on mathematical topics, including BBC's *Horizon* and Channel 4's *Equinox*. Popular topics are Fractals, Chaos, Gödel's Incompleteness Theorems and Infinity.

Particularly remarkable is the BAFTA winning Horizon episode on *Fermat's Last Theorem*. It uses the apparent simplicity of the problem, its exciting history, and the personality and passion of Andrew Wiles, to show a lay audience what mathematical research is like, and why mathematicians talk about beauty in pure mathematics. [41]

Others

Other educational movies and TV series on mathematics include *Fun and Games* on Yorkshire TV for a general/family audience and *Help your Child with Maths* on BBC which specifically targets parents [9].

More recently, *Dara Ó Briain's School of Hard Sums* doesn't use any stories or applications to make mathematics 'look' more interesting, and instead builds on presenter Ó Briain's popularity. The audience and celebrity guests are invited to solve mathematical problems, but unfortunately the solutions and underlying mathematical concepts are explained in disappointingly little detail.

Mathematical references also appear in TV series like *Star Trek*, *Doctor Who*, *The Simpsons* and many others. A play which includes many advanced mathematical ideas, though without going into much detail, is Tom Stoppard's *Arcadia*.

2.4 Digital Mathematics

The internet had a profound effect on education in the past – particularly regarding informal education outside the classroom. This is particularly suitable for popularisation.

Education is becoming increasingly more digital, and the internet is a great platform to show a wide audience how interesting and exciting mathematics is. Unlike books or newspapers, websites allow for interactivity as well as forums for discussion and collaboration. You can even filter content depending on readers abilities and background.

On the other hand, there are so many mathematics related websites that it can be hard to the particularly good ones…

Mathigon

Mathigon.org is a collection of online mathematics resources, such as highly interactive eBooks, animated slideshows, videos and lesson plans for teachers.

Compared to most other mathematics websites, the key aim of *Mathigon* is to make mathematics *look beautiful*, with countless illustrations, colourful graphics, and a clean, modern and mobile capable design.

One feature are interactive variables: readers can slide to change their value, and the following text and equations change accordingly. In other section, the user has to click certain elements of diagrams, or move a slider, for more or different content to appear. This creates a much more interactive and engaging reading experience, when compared to static textbooks.

In terms of topics, *Mathigon* focuses on advanced – but not necessarily difficult – mathematics which you wouldn't usually see at school: game theory, cryptography, fractals, group theory, graph theory and number theory, as well as origami, art and music.

I have been working on *Mathigon* since summer 2012, and the site has proven popular, with around 600 visits per day and much feedback via email or social websites. Particularly well received were the interactivity and the graphical representations of advanced mathematics:

"You've made a beautiful start, and I'll much look forward to seeing the new material online."
Sir Martin Rees, Astronomer Royal and Master of Trinity College Cambridge

"This is awesome!! Never seen a math website quite like this."
MoroccoMole1 via Reddit

"Oh my, this is the most beautiful thing I've ever seen!"
Alfred Naayem via email

"I'm so excited someone is taking up the task of making historial & interactive lessons with a narrative throughout. I'll be using this with my kids."
Brit Cruise from Khan Academy

"[...] an excellent resource for teachers, prospective maths undergrads and interested others containing a wide range of fascinating topics presented in a thought-provoking and accessible way."
Noel-Ann Bradshaw, University of Greenwich

One feature which is often requested – and which I am working on to add in the future – are more puzzles and problems for readers to solve.

Plus Magazine (MMP)

Plus is a digital magazine published by the *Millennium Mathematics Project* at Cambridge University. It *"opens a door to the world of maths, with all its beauty and applications, by providing articles [...] on topics as diverse as art, medicine, cosmology and sport"* [42]. *Plus* also includes news, book reviews, podcasts, puzzles, and careers advise for students.

It is a fantastic resource to explore how diverse mathematics is, learn about its history, and discover in how many different ways it can be used. The articles, however, are static and very print-magazine-like, not exploring the interactive possibilities which a digital platform would offer.

Nrich Website (MMP)

Nrich is also published by the *Millennium Mathematics Project*. While *Plus* above is for *learning about* mathematics, *Nrich* is for *doing* mathematics. The website offers countless interesting and fun problems, many of which have a *"low-threshold and high-ceiling"*, and are thus interesting for students with different abilities.

You can submit solutions to 'problems of the week', and some solutions are published on the website. There are also additional information for teachers and general interest article about mathematics.

Nrich aims to *"enrich the mathematical experience of all students and develop confident, creative, resourceful problem-solvers"*. Content is designed to *"build students' [...] mathematical reasoning, thinking skills and ability to take the initiative"* [43].

Mathematics Videos

There are many mathematical videos on *YouTube*, ranging from fractal zoom sequences to lectures provided by universities like MIT or Harvard. I particularly enjoy Vi Hart's channel [44], which presents fun mathematical ideas in a rapid and radically different way.

Some of the first and most inspiring videos were in the "IBM Mathematics Peep Show" created by designers Charles and Ray Eames. In beautifully animated 2-minute clips they explain the sieve of Erathostenes, topology, group theory or exponents. [45]

Khan Academy contains a great number of videos about mathematics, though mostly school curriculum related. More videos on applications of mathematics are currently under development.

Many of the principles for mathematics on TV (see previous section) can be applied to all of the videos above.

Popular Mathematics Mobile Apps

At present, there is little popular maths content for mobile devices like the iPad, despite the great potential for education in the future.

One example is *'Minds of Modern Mathematics'* [46], an interactive timeline for iPad covering 1000 years of mathematical history, created by IBM and based on the physical timeline which was part of the *Mathematica* exhibition by Charles and Ray Eames in 1961 (see below).

Panasonic's *PrimeSmash!* [47] is a game in which users have to 'smash' number bubbles into their prime factors, or identify those numbers which are prime. It illustrates prime factorisation and its uniqueness in a fun and interactive way.

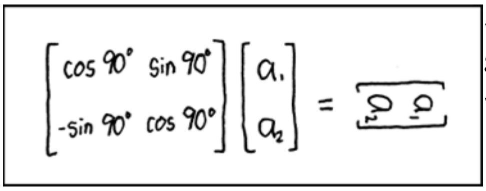
Other mathematics apps include fractal generators or wallpaper tessellation makers. Unfortunately there usually is little explanation of the equally interesting mathematical background.

An upcoming iPad app, *Numbers*, published by Touch Press with text by Ian Stewart and technology by Wolfram Research, will make the successful concept of 'popular mathematics books' even more engaging and accessible by adding high quality graphics, computations and interactive content.

Other Digital Resources

Many (non-educational) computer games require some logical reasoning (e.g. *Portal*), but very few are directly related to mathematics. One example is the German game *Mathica* [48], where players have to solve clues left behind by a deceased mathematician, in order to free his captive stepdaughter.

Another medium that can be used for popularisation is Radio – especially since it *"forces the [listeners] to visualise"*, without *"imposing a particular image"* [5]. Examples include *The Infinite Monkey Cage* hosted by Brian Cox and Robin Ince on BBC Radio 4, Marcus du Sautoy's *A Brief History of Mathematics*, Simon Singh's *Five Numbers*, and many episodes of Melvyn Bragg's *In Our Time* [49]. The distribution of radio episodes has been greatly simplified using iTunes, podcasts and web players.



from *xkcd.com/184/*

Another great new way to make mathematics fun are web comics and mathematical humour, such as *xkcd* or *Saturday Morning Breakfast Cereal*. They are targeted primarily at maths, science or engineering students, but maybe they can also be used for educational purposes in the future.

Other popular mathematics related websites include *Numberphile*, *Planet Math* and *math.stackexchange*, as well as the websites of magazines like *New Scientist* and *Scientific American*.

There are several of extensive mathematics software packages, like *Mathematica*, *Matlab* or *GeoGebra*. They can not only be used to make mathematics more interactive and visual, but they can do 'boring' arithmetic and calculations so that students can focus on the more interesting parts of mathematics. This is the underlying idea of the *Computer Based Math* project [50].

Websites like the *Wolfram Demonstrations Project* showcase the interesting things you can do with mathematics and with software [51]. In the future it might be possible to use mathematical software directly for popularisation.

2.5 Printed Mathematics

For a long time, books and magazines were the primary medium of mathematics popularisation. In recent years, however, there has been a significant shift towards videos and digital media – not only in popularisation but for almost any kind of content. Books not only appear less fun and interesting, but they require more effort to read.

This doesn't mean that books are less valuable for popularisation: Sir Timothy Gowers' *Mathematics: A Very Short Introduction* might be the best overview ever written of what mathematics, mathematical thinking and mathematical modelling mean.

Popular Mathematics Books

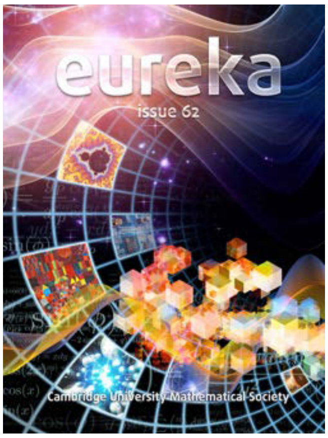
There are countless 'popular mathematics' books; particularly successful authors include Martin Gardner, Ian Stewart, Keith Devlin, Simon Singh, and Marcus du Sautoy. Mathematical books for the general public have been published much earlier – by authors including Lewis Carroll.

One of the most inspiring books is Douglas Hofstadter's Pulitzer Prize winning *Gödel, Escher, Bach: An Eternal Golden Braid*. It includes many mathematical ideas such as symmetry, logic and recursion, but is primarily about cognition, philosophy, and the meaning of *knowledge* itself.

Many books focus on one particular topic of mathematics, such as Fermat's last theorem, fractals and chaos, or on applications, historical aspects or certain mathematicians. Other books cover a range of related topics, such as Ian Stewart's *Seventeen Equations that Changed the World* or *The Penguin Book of Curious and Interesting Numbers*.

There are also many books with mathematical puzzles and problems – though Howson and Kahane doubt the value of books which don't also *"introduce the reader to elegant, powerful,* mathematical *approaches to problem solving"* [5].

Popular Maths Magazines



Many of the big popular science magazines print regular articles on mathematics, including *Scientific American*, *New Scientist*, *PopSci* and many others. At a higher level – for undergraduates, professionals or teachers – there are journals like *Nature*, *The Mathematical Gazette*, *Mathematics Magazine*, or *Eureka*.

Accromath is a colourful and engaging magazine published (in French) by the Université du Québec. It is targeted at high school students and teachers, and consists of articles on topics like the Reuleaux triangle, knots, fraud detection, or cellular automata. Articles are complemented by short biographies and problem sets. [52]

Magazine articles are particularly suitable for providing 'glimpses' of mathematical ideas and current research, without writing an entire book. Magazines can offer a combination of many different types of articles, allowing the reader to pick those which seem most interesting, and can have a very colourful and engaging design.

Maths Columns in Newspapers

It is very rare for newspapers to write about mathematics: groundbreaking mathematical results happen infrequently, and usually in topics which are too difficult to explain to a general audience, and are unlikely to have an immediate application relevant to the readers. Mathematical advances happen gradually, not overnight, and editors may think that there is little public interest in these topics. [10]

The most dramatic effect of these problems is that, to the general public, mathematics does not seem like a *'living discipline'*, where research is still happening, which is required in science, engineering and technology, and which could be worth pursuing a career in.

Lynn Steen suggests in [10] to not use mathematicians as publicists, to connect theorems to topics like the economy, health or the environment, to focus on the *"spirit of mathematics"* rather than *"literal truth"*, and to connect news with school mathematics which is common to all readers.

Another great opportunity for mathematical news, particularly local, are competitions like the IMA, prizes like the Fields Medal or the Abel Prize, or mathematical conferences.

2.6 Exhibitions, Roadshows and Walks

There are science centres or museums in most big cities, but they rarely focus on the mathematical aspects of science. In recent years, however, the number of exhibitions and museums dedicated to mathematics has greatly increased.

To be successful both in entertaining visitors and teaching about mathematics, exhibitions need to consist of engaging activities as well as offering information about the mathematical background and applications. Howson and Kahane [5] argue that *"activity, colour, beauty, etc. should be there, but should never be allowed to supplant serious mathematical content and purpose"*. On the other hand, some of the exhibitions below focus exclusively on mathematical imagery and are just as fascinating to visit.

Topics which are particularly suitable to be explained in museums include kinematics, regular polyhedra, symmetry, graph theory, or soap bubbles.

Mathematica: A World of Numbers ... and Beyond!

One of the first mathematical exhibitions was created in 1961 by the designers Charles and Ray Eames and IBM, to be part of the California Museum of Science and Industry. Since 2000 the exhibition is part of the New York Hall of Science, and duplicates have been created elsewhere. [45]

The exhibition explains a range of advanced mathematical ideas using interactive activities, stunning graphics and spectacular models, such as celestial mechanics, soap bubbles and minimal surfaces, topology and the Möbius strip, probability, calculus, logic and projective geometry [53]. Part of the exhibition is a large ‘timeline wall’, which has been converted into an iPad app (see above).

MoMath New York

The *Museum of Mathematics* opened in 2012 in New York, and is the only dedicated mathematics museum in North America. It consists of around 30 highly interactive exhibits, such as a *Square-Wheeled Trike*, a walk-in *Hyper Hyperboloid*, or a *Tessellation Station* [54].

MoMath received great reviews from visitors and press. It is, however, very much a *childrens*' museum. At times, it seems to fall into the trap of focusing on exciting activities rather than the underlying mathematics. These activities may be helpful, or necessary, to create general interest and appeal, but we want visitors to remember surprising and beautiful mathematics – not the ability to play games.

IMAGINARY

IMAGINARY is a travelling exhibition developed in 2008 for the *Year of Mathematics* in Germany, and which has visited more than 60 cities around the world since then. [55]

The exhibition consists of beautiful and spectacular mathematical images and sculptures, as well as short videos. Visitors also create their own algebraic surfaces using a computer, or explore a virtual 3D mathematical world.

Other Exhibitions

The most interesting mathematics exhibition I have visited was the *Mathematisches Kabinet* at the *Deutsches Museum* in Munich. The creators did not 'trivialise' advanced mathematics, but explained double pendula, shapes of constant diameter, knots, various tessellations, mazes, fractals, chaos, computational complexity, and many other topics with great clarity.

While children and more superficial visitors can simply look at the colourful images and play with various demonstrations, interested visitors can read detailed explanations on boards and an extensive companion book. [56]

There are a number of other mathematics museums and exhibitions in Germany. The famous *Mathematikum* in Gießen is the first interactive mathematics museum in the world [57]. The *Arithmeum* in Bonn explains the history of 'calculating' from ancient artefacts to some of the first mechanical computers and modern technology [58]. The *Mathema* exhibition in Berlin (2008/2009) consisted of experiments and demonstrations showing applications of mathematics, as well as its beauty and philosophical background. Content was arranged in seven sections: *Numbers*, *Geometry*, *Functions*, *Chance*, *Limits*, *Art* and *Children* [59].

Experiencing Mathematics is an international travelling exhibition initiated by UNESCO in 2005. It consists of hands-on activities, graphics and videos, and is targeted at students and teenagers, parents and teachers [60]. The exhibition has taken place in many developing countries, where visitors wouldn't usually have had access to similar content. An online version of the exhibition exists at *experiencingmath.org*.

Mathematics of Planet Earth 2013 is an international collaboration of more than 100 universities and organisations, who are offering relevant outreach activities throughout the year, such as workshops, exhibitions and public lectures. It also includes the creation of open source exhibition material which is or will be shown at many museums around the world. [61]

A dedicated mathematics museum in the UK, MathsWorldUK, is currently under development [62]. An extensive list of other mathematics museums and exhibitions can be found at *mathfactory.org/Similar+Institutions*.

Roadshows and Other Activities

When a full-scale exhibition is not possible, there are many roadshows to choose from. Examples include *Math Midway* organised by MoMath in the US [62] or the *Hands On Maths Roadshow* by the Millennium Maths Project in the UK [63].

Maths in the City offers walking tours of Oxford or London, showing how mathematics is part of *"buildings, roads, cars [...], power, water, sewage and transport systems"* [64].

There are also numerous mathematics shows and performances, such as *Maths Busking* and *The Number Ninja*.

Summary and Conclusion

The prevailing public opinion about mathematics is that it is boring, irrelevant and dry. In fact, there are countless real world applications of mathematics, not to mention the intrinsic value of logical reasoning and the cultural value of mathematical beauty and history.

Mathematical research is fundamental to ensure continued scientific, technological and economic progress – therefore it is particularly concerning to see so many children being deterred by school mathematics. Mathematics popularisation can attempt to bridge this gap.

While some popularisation projects only *teach about mathematics*, including its applications, history and philosophy, other projects want to actively engage their audience in problem solving and mathematical thinking. Throughout this report there were valid arguments and successful examples of both.

In almost all cases, there is something other than *mathematics* to capture the audience's attention and imagination – ranging from applications like cryptography to games and activities, music, art or stories. But it is important not to lose focus of the underlying mathematics, which might be beautiful, insightful, enlightening, or simply unexpected.

In recent years there has been a fantastic growth in the number of popularisation projects, ranging across a wide number of different media, audiences and approaches. However, for greatest effect, it is important that some of these ideas also find their way back into the classroom.

Mathematics is the language of nature, of science and technology, and of the world around us. Popularisation gives everyone the opportunity to understand and appreciate this universal language.

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