

Institution: University of Oxford
Unit of Assessment: 10, Mathematical Sciences
Title of case study: Finding Moonshine: engaging the public through mathematical research
<p>1. Summary of the impact</p> <p>By using the progress of his own research over the course of a year as a major narrative theme, in <i>Finding Moonshine</i> Marcus du Sautoy provides the public with unique insight into the content and nature of his mathematical research programme. The success of the book, published in 2008, in conveying the essence of cutting edge research, in elementary terms, attracted the attention of broadcasters and policymakers and provided a platform from which du Sautoy has been able to expand his public engagement activities to reach millions of people through TV, radio, public lectures, social media and interactive projects. His three part documentary <i>The Code</i> stimulated over a million viewers to play Flash games based directly on mathematical concepts. The phenomenal success of his unique brand of engagement in awakening an interest in mathematics, in both young and old, has had a great impact on society.</p>
<p>2. Underpinning research</p> <p>Marcus du Sautoy has been at the University of Oxford since 2001, first as a Royal Society University Research Fellow (until 2005), then as Professor of Mathematics (2005-8) and, since 2008, as the Charles Simonyi Chair for the Public Understanding of Science. In the period 2005-6, du Sautoy's research programme, centred on zeta functions and Higman's PORC conjecture.</p> <p>The zeta function of a group G is defined as the sum of the Dirichlet series whose n^{th} term is $a_n n^{-s}$ where a_n is the number of subgroups of index n in G. Such zeta functions have an Euler product decomposition in which the p-local factor is the zeta function enumerating subgroups of p-power index in G. Nilpotent groups are natural objects of study in this context because of their polynomial subgroup growth. Du Sautoy's work with Grunewald (Heinrich-Heine-Universität Düsseldorf) shifted the paradigm of comparison from analytic number theory to algebraic geometry, specifically zeta functions associated to algebraic varieties. The mathematical significance of du Sautoy's programme of work with Grunewald was recognized by his invitation to speak at the International Congress of Mathematicians in Zürich in 2006. The corresponding paper, [1], reports on "progress and problems concerning the analytical behaviour of the zeta functions of groups and rings" and provides a technical mathematical presentation of this strand of the research described in <i>Finding Moonshine</i>.</p> <p>Another strand of du Sautoy's research programme during 2005-6 concerned his conjecture that all zeta functions of groups satisfy functional equations. However, during the period, explicit calculations uncovered a counterexample. The mathematical details are published in [2].</p>
<p>3. References to the research</p> <p>*[1] M du Sautoy and F Grunewald, Zeta functions of groups and rings. <i>International Congress of Mathematicians</i> Vol II, 131–149. Eur. Math. Soc., Zürich, 2006 http://www.icm2006.org/proceedings/Vol_II/contents/ICM_Vol_2_07.pdf</p> <p>*[2] M du Sautoy and L Woodward, Zeta functions of groups and rings. <i>Lecture Notes in Mathematics</i> Vol 1925, 2008. ISBN: 978-3-540-74701-7</p> <p>The asterisked outputs best indicate the quality of the underpinning research. [1] resulted from du Sautoy's invited lecture at the ICM in 2006 and [2] is a research monograph.</p>
<p>4. Details of the impact</p> <p>Published in 2008, <i>Finding Moonshine</i> created a channel via which du Sautoy's research has had huge impact on society, stimulating interest in, and engagement with, mathematics. The ultimate</p>

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beneficiaries have been millions of members of the general public whose mathematical curiosity has been awoken.

Finding Moonshine provides the general public with a unique insight into mathematical research. As the story of the classification of finite simple groups unfolds, du Sautoy charts the progress of his own research, month by month, during the year following his 40th birthday. Its publication cemented Marcus du Sautoy's position as an outstanding expositor of mathematics and provided a platform from which he expanded his public engagement activities. Millions of people have subsequently watched his TV shows, listened to his radio programmes, played his Flash games and interacted through Facebook. He has been able to use his position as a leading mathematician and public figure to engage with Government. Throughout he has maintained close contact with his audiences and developed new ideas through more intimate activities such as 'Maths in the City' and 'Pi Day'.

How research underpins impact

Marcus du Sautoy's second popular book, *Finding Moonshine: A Mathematician's Journey into Symmetry* was published in 2008. Although primarily concerned with the story of the classification of the finite simple groups, du Sautoy's own research is central to the narrative. The story begins in 2005, on his 40th birthday, and uses the literary device of being divided into twelve chapters, one for each month of the year. Amid many diversions into the (often colourful) lives of famous mathematicians and stories of major mathematical discoveries, it has two narrative strands. The first is the story of the classification of the finite simple groups. The second is the progress, month by month, of du Sautoy's own research. As part of this second strand, he describes the problems that he is working on and something of the process of solving, or, in the case of the problem that he first describes, not solving, them. He describes Higman's PORC conjecture and his growing scepticism about its validity. We also see his programme develop: he and a research student demolish one of his conjectures by exhibiting a group for which the corresponding zeta function does not satisfy a functional equation - a concept elegantly explained in terms of palindromic symmetry - as the conjecture predicts, and so the question is refined. His research, and the process of research, are thus brought directly to the reader. Crucially, the book demonstrated that, rather than cherry-picking pieces of mathematics that are easy to explain, du Sautoy is able to explain the mathematical concepts that lie at the heart of his research in a way that is accessible and engaging. The next step was to provide his audiences with the opportunity to go beyond the passive process of reading and to actually participate in the mathematics. This required multiple media, but combining his abilities as a broadcaster with his deep knowledge and boundless curiosity as a researcher he developed ideas based on these same mathematical concepts into TV shows with accompanying web-based Flash games.

Nature and extent of impact.

The impact of *Finding Moonshine* has been both direct and indirect. It has been translated into ten languages and has sold over 62,311 copies worldwide [A]. The Fields medallist Professor Sir Timothy Gowers wrote in his review for the *Times Higher Educational* supplement [B]: "*If you are genuinely curious to know what it is like to be a mathematician, there is now a better way of satisfying your curiosity: read Finding Moonshine.*" The publication of the book gave du Sautoy the platform to promote and explain the importance of group theory to a wide audience, with diverse mathematical backgrounds, as evidenced by many of the comments from readers left on du Sautoy's blog [C]:

- "*I'm a former student of maths. I abandoned my studies 20 years ago. Recently, my wife gave me your book about symmetry as a present. Now I am enjoying the reading greatly. You awakened in me a kind of longing for maths. A math worm that was sleeping for years. [...] I just wanted to thank you for making Mathematics so appealing.*"
- "*Just finished this book. It really is a very good read even for those who have a little understanding of maths. Considering I only have a GCSE I didn't find it too bewildering.*"
- "*I just finished reading Finding Moonshine in the dead of night last night :) I so enjoyed it [...] Now I see symmetry everywhere - what a joy!*"

TV and Radio. With the success of *Finding Moonshine*, du Sautoy found himself in increasing

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demand as a broadcaster. A string of appearances on TV and radio, in which he explained the importance, and excitement, of mathematics followed, including:

- The Story of Maths (4 part series on BBC4, Autumn 2008): Episode 1, 0.58 million viewers;
- Horizon: How Long is a Piece of String - Presented by comedian Alan Davies and featuring Marcus du Sautoy on BBC2 on 17th November 2009: 2.11 million viewers;
- Horizon: What Makes a Genius - on BBC2 on 17th February 2010: 1.76 million viewers;
- A Brief History of Mathematics - a ten part series profiling famous mathematicians on BBC Radio 4 in June 2010.

(TV viewing figures here and below are taken from www.barb.co.uk/viewing/weekly-top-30.)

One of Horizon's viewers commented on du Sautoy's blog [C]: *"Your enthusiasm is infectious. I repeated your explanation of Euclid's Prime Number Proof to my 9 and 12 year olds and they were gripped. I didn't understand about mathematical proofs until after I left school! Thanks for a great piece of work."*

With such clear evidence of his appeal as a broadcaster and of his ability to present complex mathematical concepts, right up to the cutting edge of research, in a way that was accessible to audiences from very mixed mathematical backgrounds, he next went beyond the traditional format of these programmes to develop new shows, supported by materials that exploit a range of electronic media, which appeal to audiences with a much wider demographic profile. Importantly, the public actively participate in the mathematics. Building on the success of *Finding Moonshine*, the material of these shows is directly based on mathematical concepts, especially the prime numbers and symmetry that lie at the heart of du Sautoy's research.

The first such show was *The Code*, a three part documentary series on BBC2 which started on 27 July 2011. Viewing figures for the three episodes were 1.75 million, 1.53 million and 1.33 million. Viewers of *The Code* were invited to participate in an interactive mathematical treasure hunt based on the academic ideas presented in the programmes. The treasure hunt involved four web-based Flash games, produced by the company *Six to Start*, who state [D] *"all of the games are tied directly into concepts shown in the show"*, focusing on mathematical concepts such as symmetry and prime numbers, hunting for clues in the programmes, solving riddles, finding examples of prime numbers in everyday life and completing a complex mathematical quiz book. They add that over 1 million people played the Flash games, playing for an average of 24 minutes, and more than 100,000 took part in the treasure hunt challenge. The level of engagement by viewers was staggering, as all of the elements of the treasure hunt involved dedication and complex mathematical concepts. According to the *Six to Start* Executive, reported in an external blog [E], there are *"300,000+ interactions on the Facebook fan page, 1000+ photos, videos, 3D models, and a wiki with 100,000 views and 2000+ edits – all created by users"*. An appraisal of the treasure hunt on the same blog emphasises the significance of the engagement: *"The whole thing was really involved and quite complex, not to mention on a traditionally unpopular subject, maths, so over 100k players for the meta-puzzle is impressive [...] it does seem like quite an achievement."*

The opportunity to engage a quite different kind of audience arrived when du Sautoy was chosen as co-presenter of the comedy-maths show, *Dara Ó Briain's School of Hard Sums*. First aired on Dave on 16th April 2012, it attracted 1.7 million viewers. According to the Executive Producer of the show [F] *"[it is] the most watched completely new title in the history of the channel"* with *"more than double the normal ratings in its slot with 555,000 viewers for episode one"*. She adds that proof that viewers have engaged with the maths that du Sautoy introduces on the show is that *"the homework questions were viewed a staggering 442,124 times! The title accounted for almost a quarter of all page views when it was on air (2,030,796 total page views) and has recently been re-commissioned by Dave"*.

Recognition of the huge educational potential that du Sautoy had unlocked came in a speech [G] of Michael Gove, Secretary of State for Education: *"Computer games developed by Marcus Du Sautoy are enabling children to engage with complex mathematical problems that would hitherto have been thought too advanced. I am sure that this field of educational games has huge potential for maths and science teaching"*.

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Maths in the City and Pi day. Public engagement activities must be continually refreshed if they are to continue to have impact. Recognising the importance of a two-way dialogue, and also the value of smaller scale, more intimate, projects than his TV shows, in 2010 du Sautoy began working with a team from the University of Oxford's Department of Continuing Education to create a way to reach out to the public with maths, ensure engagement with the subject and open a two-way dialogue with participants. The result was the Maths in the City project: a website with a user forum heavily involving social media, and walking tours around Oxford and London pointing out examples of maths in everyday life. Just as when he describes outings with his son in *Finding Moonshine*, symmetry, inevitably, plays a central role. Du Sautoy helped to design the free tours and materials and led some of them before handing over to students from the Oxford Mathematical Institute, whom he had trained. Funded by the EPSRC, the tours, which were attended by adults and school groups from as young as Key Stage 3, were a huge success with over 2500 people engaging via social media, over 460 people attending the tours and over 130 examples of 'maths in the city' from around the world posted on the website. The Maths in the City project has been so successful, that the same format is being used in the training of mathematics teachers in China.

Du Sautoy has continued to work with the University of Oxford's Department of Continuing Education to create events that not only broaden the knowledge of the participants, but also their approach to maths. Through the use of online communication, these events allow participants to engage both during and after the live event. The first event, Pi day, which took place in March 2013, made innovative use of social media in arranging for participants to 'rediscover Pi' through experiments. According to <http://oxfordconnect.conted.ox.ac.uk>, around 2000 participants from 17 different countries took part.

Sale of Groups and Common Hope. In a completely different direction, in October 2012, du Sautoy offered opportunities to name nilpotent groups appearing in his research in recognition of contributions to charity. Through this direct application of his research, du Sautoy sponsors the Common Hope Charity that supports orphanages in Guatemala. Amid widespread, and very positive, publicity for mathematics, such as the article [H] in *The Times*, he also offered one of the groups to Queen Elizabeth II in honour of her Diamond Jubilee.

5. Sources to corroborate the impact

- [A] Email from executive from Greene & Heaton, confirming sales details for *Finding Moonshine*. Copy held by the University of Oxford.
- [B] Review by Timothy Gowers of *Finding Moonshine* for the Times Higher Education supplement: <http://www.timeshighereducation.co.uk/story.asp?storycode=400699>.
- [C] Comments from the Finding Moonshine blog, indicating the reach of the impact of du Sautoy's work: <http://findingmoonshine.blogspot.co.uk/>.
- [D] Email from Six to Start Executive (the company that produced the Flash games and treasure hunt), describing audience engagement. Copy held by University of Oxford.
- [E] View of The Code treasure hunt: <http://marthasadie.wordpress.com/2012/03/21/notes-from-sxswi-adrian-hon-creating-the-code-a-bbc-transmedia-documentary-thecode/>.
- [F] Email from Executive Producer, The School of Hard Sums. Copy held by University of Oxford.
- [G] Speech by Michael Gove, 29 June 2011 at the Royal Society, demonstrating the impact on school children: <http://www.education.gov.uk/inthenews/speeches/a00191729/michael-gove-speaks-to-the-royal-society-on-maths-and-science>.
- [H] Times article on the gift of a group to Her Majesty the Queen, <http://www.thetimes.co.uk/tto/science/article3566284.ece>.