

Institution: University College London		
Unit of Assessment: 10 - Mathematical Sciences		
Title of case study: Public and media impact arising from mathematical research at UCL		
Period when the underpinning research was undertaken: 2011 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Hannah Fry Helen Wilson	Senior lecturer Professor of Applied Mathematics	2012 – Present 2004 – Present
Adam Townsend	Postdoctoral researcher	2012 – 2016
Period when the claimed impact occurred: 1 August 2013 to 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of Impact (indicative maximum 100 words)		
<p>UCL researchers Dr Hannah Fry and Professor Helen Wilson made complex mathematics accessible to millions among the general public with popular talks, lectures, books and TV programmes. They simultaneously demonstrated how wide-ranging mathematical modelling (from crime to pandemics and from chocolate to corn starch) has impact in the real world. This has inspired interests, informed decision making, encouraged school students to consider pursuing mathematics further and sent an important message about mathematics not being an all-male preserve. It has also helped dispel misinformation circulating during the coronavirus pandemic. Since the programme of engagement with Maths started, applications to UCL Mathematics have increased by 46% to 2436 between 2013/14 and 2019/20.</p>		
2. Underpinning research (indicative maximum 500 words)		
<p>Dr Hannah Fry uses mathematics to address social questions, from human relationships with algorithms; to crime; to outbreaks of infectious disease. Professor Helen Wilson develops mathematical models of complex fluids, with wide-ranging industrial applications.</p>		
<u>Human relationships with algorithms</u>		
<p>As society becomes more reliant on technology, there is an increasing demand for complex algorithms that can tackle increasingly sophisticated tasks. However, there is a critical need and moral duty to better understand the implications and, more importantly, the limitations of automation. Fry's 2018 book, <i>Hello World: How to be Human in the Age of the Machine (R1)</i>, does just that. Using examples such as medicine, self-driving cars and justice, she argues powerfully that algorithms must be integrated with human decision making rather than used as a substitute. The book shows the strengths of algorithms, for example, the chapter on crime, which includes a mathematical model developed by Fry and colleagues, to describe the relationship between crime and location, and how burglars decide on the optimal activity level of a street to target (R2). The book also highlights their weaknesses, using Fry's mathematical insight to explain why artificial intelligence and machine learning are fundamentally unsuited to making many important decisions without human oversight.</p>		
<u>Human behaviour underlying disease transmission</u>		
<p>In 2018, the BBC commissioned a project to develop a better understanding of how an infectious disease like flu can spread, by collecting and interpreting data on how people travel and interact. The project consisted of two parts; a BBC documentary and an accompanying smartphone App ("BBC Pandemic"), from which users contributed three</p>		

types of data; their age, location, and movement. This data was then used to develop a mathematical model of disease spread; how a potential pandemic might unfold; and the effect of certain control measures, such as handwashing (R3). In collaboration with researchers from the University of Cambridge and the London School of Hygiene and Tropical Medicine, Fry led the documentary and nationwide recruitment campaign, encouraging members of the public to participate in the project. Fry's additional role was to explain, in an accessible way, the mathematics involved. Follow-on work in response to the Covid-19 pandemic has published population contact matrices (a vital tool for epidemiological modellers), giving age-specific patterns of movement and social mixing, classified by key characteristics such as contact type (conversational or physical) and setting (home, work, school, other) (R4). Mathematical models built from this base, demonstrated that the most effective strategy against Covid-19 involves a combination of isolation and full contact tracing (R5).

Mathematical models of complex fluids

Professor Helen Wilson has a broad platform of research across complex fluids, including those which become thinner or thicker under flow. The team studied the chocolate fountain. Molten chocolate gets mildly thinner under flow. In their study, Wilson and co-author Townsend divided the flow within a chocolate fountain into three distinct dynamical regimes: 1) being pumped to the top through a pipe, 2) flowing as a thin film over the tiered domes, and 3) falling freely as a curtain. They showed that the dome flow was driven by a balance between gravity and viscosity, and that the dominant effect in the falling curtain was the inwards pull of surface tension (R6).

3. References to the research (indicative maximum of six references)

- R1. **Fry H.** (2018) *Hello World: Being Human in the Age of Algorithms* (1st. ed.). W. W. Norton & Company. Available on request.
- R2. Frith M., Johnson S, **Fry H** (2017) Role of the street network in burglars' spatial decision-making, *Criminology* 55:344-376. doi:10.1111/1745-9125.12133
- R3. Klepac P., Kissler S., Gog J. (2018) Contagion! The BBC Four Pandemic – The model behind the documentary. *Epidemics* 24:49-59 (2018). doi:10.1016/j.epidem.2018.03.003
Note that Fry is not an author on the first pandemic paper, however, is specifically acknowledged for her “contributions to this project's specification and the collection of the data, as well as for [her] assistance in developing of the ideas presented in this article”.
- R4. Klepac P., Kucharski A., Conlan A., Kissler S., Tang M., **Fry H.**, Gog J. (2020) Contacts in context: large-scale setting-specific social mixing matrices from the BBC Pandemic project. *medRxiv*. doi:10.1101/2020.02.16.20023754
- R5. Kucharski A., Klepac P., Conlan A., Kissler S., Tang M, **Fry H.** (2020) Effectiveness of isolation, testing, contact tracing, and physical distancing on reducing transmission of SARS-CoV-2 in different settings: a mathematical modelling study. *Lancet Infect Dis* 20:1151-60. doi:10.1016/S1473-3099(20)30457-6
- R6. **Townsend A., Wilson H.** (2016) The fluid dynamics of the chocolate fountain. *J. Phys. B* 37. doi:10.1088/0143-0807/37/1/015803
- Note that some of the impact occurred before publication: the project was complete in 2012 but the publication followed later.

4. Details of the impact (indicative maximum 750 words)

UCL's research has led to impacts in three key areas: algorithms, modelling disease outbreaks, and non-Newtonian fluids. Through research, its application and public engagement, Dr Hannah Fry and Professor Helen Wilson have cultivated a greater awareness of the use of mathematics applied to real-world scenarios. Engagement via broadcast and press media as well as social media have increased the appreciation of mathematics in a global audience of millions. Outreach engagements with schools have had a strong and positive impact on encouraging further studies in mathematics among GCSE

and A-level students. By presenting female mathematicians as role models, they demonstrated that mathematics is not a purely male pursuit.

Improving public understanding of the applications of mathematics: algorithms

The use of spatial decision-making in crime prevention (R2) is one of the chapters in the book *Hello World* (R1) that has engaged over 140,000 readers (S1). It was also discussed by Fry in two YouTube videos “Being Human in the Age of Algorithms” and “The Mathematics of Crime and Terrorism” which were watched approximately 30,000 and 700,000 times, respectively (S1). The videos have stimulated public interest in mathematics with viewers commented “I’m studying safety and security right now and this is really interesting”, “This makes me want to understand maths better than I do” (S1).

By discussing the benefits of algorithm applications and the consequences of their misuse in *Hello World* (R1), Fry has encouraged changes in the understanding of maths among readers on various career paths, as evidenced by feedback: “I’ve just finished reading your book *Hello World* and it’s an amazing read. I absolutely back everything you say, spot on! (...) I’m slowly changing the mind-set of the global organisation I work for and will personally purchase a number of your books to give as gifts to global CEO and CTOs” (S2); “(...) your book has provided a valuable contribution to my thought process, both personally and for teaching students” (S2);

“I posted a short blog referencing you as I saw a powerful link between the challenge you present and the concepts, I have been encouraging execs to think about the distinction between decisions and choices” (S2);

“(...) I am a computer scientist and I am very sceptical about AI, and I really thank you for pointing out the flaws of AI and how to use AI in a way that is truly advantageous” (S1).

Improving public understanding of the applications of mathematics: how disease is spread

In the project *Contagion! The BBC Four Pandemic*, engagement with the public was a key part of the research itself. Fry’s contribution to the BBC Four’s *Contagion!* citizen science project encouraged sign-ups from almost 30,000 participants and over 10,000 App downloads from the Google Play store (S3). The *Contagion!* documentary was aired in March 2018 with a viewership of 547,000, making it the most watched show during its debut week (S3). Fry has been acknowledged for using mathematical modelling to improve public understanding of how a pandemic is spread (R4). She played “a strong role in preparing for future potential pandemics, by providing movement and interaction data for over 30,000 people” (S4). The Commissioning Editor for Natural History and Specialist Factual commented on the wide public interest and involvement in the project thanks to which “(...) each download is a step closer to being more prepared for when the next pandemic does strike” (S3). Indeed, in 2020, the *Contagion!* documentary continued to encourage discussion on how lockdown could help reduce the reproduction rate (R rate), and mathematical models developed for the *Contagion!* project continued to be used by media outlets such as BBC *Science Focus* and *Business Insider* to communicate the importance of hand washing in the current Coronavirus pandemic. As such, there has been a cascade of information from *Contagion!* being used to change public attitudes.

Most recently, the *Contagion!* documentary has been selected for re-broadcast in 6 other countries (Sweden, Norway, Switzerland, Turkey, Taiwan, Hong Kong) to better inform the public and quell misinformation regarding the pandemic caused by SARS-CoV-2 virus (S5). The CEO of Magnify Media commented “(...) an intelligent and informative documentary, but it’s also a timely one in the light of the misinformation and uncertainty surrounding the coronavirus. *Contagion!* is a sensitively made programme that explains how pandemics evolve and move around communities, based on reliable modelling techniques and technology” (S5).

Fry continued using mathematical models (R5) to explore the future effect of COVID-19 in BBC’s *Coronavirus: A Horizon Special*. The programme was watched live by 1,800,000

people and was referred to as “[containing] more clear and concise scientific fact in the first five minutes than we’ve had in the last month or so” and “the most fascinating and informative thing I have seen about COVID-19” by viewers on Twitter (S6). The programme served as an exemplar of contact tracing with key learning reported by the Scientific Advisory Group for Emergencies (SAGE) (S7).

Inspiring uptake of mathematics among school students, especially on girls

Fry’s principal contribution to inspiring the next generation of mathematicians comes from the research she carried out that led to her book *Hello World* (R1), which has sold 143,000 copies worldwide, and its subsequent engagement events. Recognised for her “qualities which are meaningful to young people considering careers in STEM subjects”, Fry was awarded the 2018 Royal Society Insight Investment Science Book Prize. In 2019, Fry presented the Royal Institution’s Christmas Lecture series, largely based on the book, and including discussions on spatial algorithms from her earlier research (R2). The Christmas Lecture series was broadcasted on national television as well as online, receiving over 1,800,000 views in total across the episodes (S8). Due to demand (the live event was oversubscribed 20-fold), the lectures were also live-streamed at 18 school venues across the UK. In addition, Fry’s original ideas detailed in the book *Hello World* inspired the Christmas Lecture’s Self-Driving Cars Debate Kit which was distributed to over 2,000 teachers and partners (including over 1,000 schools) (S8). After using the kit, teachers said it had benefited the students for its “use of technology and gets students to think about areas of employment for the future” and that it put “STEM learning in a real-life context” (S8). An associated event online called “I’m a Mathematician Christmas Lectures Zone” saw 1,156 participants from 55 schools take part. It was highly successful in stimulating students’ interest, with UCL academics providing more than 40 answers and over 200 lines of live chats addressing questions mainly about education and careers in mathematics/STEM. This direct engagement with UCL academics motivated many students. One stated, “I have loved finding out about your inspirations and it has motivated me to do better” (S8).

Since Wilson and Townsend’s research on the fluid dynamics of the chocolate fountain in 2012 (R6), the modelling described in the paper has been used as a way to engage interest in mathematics, particularly among secondary school students. The paper has been downloaded directly over 28,000 times and been shared in at least 20 news outlets globally, including the *Washington Post*, *Daily Mail*, *The Independent*, the *Smithsonian Magazine*, *Corriere della Serra* and *Wired Italy* (S9). In particular, its coverage in *First News*, a national newspaper for children, has reached a readership of 2,235,888 (S10). Delivered as part of an interactive activity, the chocolate fountain demonstration has been taken to 14 school events and 8 large multi-school events since 1st August 2013, inspiring over 5,250 students in the process (S11).

When Wilson and Fry presented their research on chocolate and crime (respectively) at the Institute of Mathematics and its Applications (IMA) 16+ lectures, a survey revealed that 95% of the 126 attendees gained a greater awareness of how maths is applied to real life and 36% are more likely to consider studying maths at university (S12). Further impact on the attending students can be demonstrated from this quote from one Head of Maths who stated “(...) some of the talks engaged our students and more than usual of our top set chose to take Further Maths as well as Maths for A-level” (S13).

To inspire girls into mathematics, both women have presented the underpinning research at a series of events, including the Royal Institution’s “Celebrating Women in Mathematics” (2014 and 2015) and the UCL “Inspiring Women in Mathematics” events. As one teacher commented “our journey home on the tubes was full of Maths Chat. It was wonderful to hear the conversations that were occurring between 13/14-year-old girls”. Many attendees were also inspired to pursue mathematics for A-levels and at university; one noted “(how...) useful the event was in allowing us to think about pursuing maths at A level or University. I have definitely been persuaded and have already looked at careers in operational research. I also

believe that education facilities everywhere should hold events such as this to help teens to realise that a career like maths has hundreds of opportunities” (S13).

Fry’s achievements in public engagement were recognised by the IMA and the London Mathematical Society (LMS) with the Christopher Zeeman medal, the highest award for the Communication of Mathematics in the UK. Nominations cited early dissemination of the research, which eventually formed the book *Hello World*. Excerpts from the citation for the award state “Hannah Fry is a truly outstanding ambassador for mathematics and it is fitting that she is awarded this prize in acknowledgment of her remarkable impact” for “(...) her most significant achievement (which) is to have inspired a generation of girls in a way that has not been done before” (S14).

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. Supporting statement from Literary Agent at Janklow & Nesbit UK corroborates number of sold copies of *Hello World* book; YouTube website for “Being Human in the Age of Algorithms” and “The Mathematics of Crime and Terrorism” videos and viewers comments corroborate viewership number and statements provided.

S2. A selection of *Hello World* readers’ emails to Hannah Fry corroborate statements provided.

S3. Article published on BBC Media Centre website (22/03/2018) and “Weekly top 10” report corroborate the number of participants in *Contagion!* project and viewership of the programme.

S4. Commentary and review of BBC Four *Contagion!* programme published on MedicalXpress website (22/03/2018) corroborate statement provided.

S5. Article published on TBI (12/03/2020) corroborates statement from CEO of Magnify Media and that the *Contagion!* documentary was sold to European, Asian broadcasters.

S6. Announcement about “Coronavirus: A Horizon Special – Part II” programme published on Northbank Talent website (18/05/2020) corroborates statements provided.

S7. Report by SAGE corroborates using BBC Pandemic data to model the impact of isolation, testing, contact tracing and physical distancing on reducing transmission of COVID-19 in different settings.

S8. Supporting statement from Series Producer at Windfall Films, interim evaluation report on “Self-Driving Cars Debate Kit” and report “2019 Christmas Lectures Zone (CLZ): Secrets and lies” corroborate viewership of Christmas Lecture series, Fry’s influence on “Self-Driving Cars Debate Kit” and details on CLZ, respectively.

S9. Overview of attention for article “The fluid dynamics of the chocolate fountain” published in European Journal of Physics (11/2015) corroborates number of downloads and features in global news outlets.

S10. Data on “First News” readership corroborates number provided.

S11. A list of outreach activities related to the chocolate fountain talks corroborates number of the chocolate fountain demonstrations within REF period.

S12. Analysis of delegate questionnaires from IMA 16Plus Lectures (06/2018) corroborates impact of lectures on attendees’ awareness of mathematics and intention to study mathematics at university.

S13. Article in Sutton & Croydon Guardian (01/03/2015) and supporting statement from Head of Maths at Archbishop Tenison’s CE High School corroborate statements provided.

S14. IMA award announcement corroborates the award of 2018 Christopher Zeeman Medal to Fry and statements provided.