

Institution: University of Nottingham (UoN)		
Unit of Assessment: 9		
Title of case study: Sixty Symbols: Communicating Research via YouTube Videos		
Period when the underpinning research was undertaken: 1 Jan 2000 - 31 July 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by the submitting HEI:
Michael Merrifield	Professor	1999 – present
Philip Moriarty	Professor	1994 – present
Antonio Padilla	Professor	2006 – present
Edmund Copeland	Professor	2005 – present
Meghan Gray	Dr	2004 – present
Clare Burrage	Professor	2011 – present
Omar Almaini	Professor	2004 – present
James Sharp	Dr	2003 – present
Richard Hill	Dr	2004 – present
Laurence Eaves	Research Professor FRS	1976 – present
Period when the impact occurred: 1 August 2013 to 31 July 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact		
<p>In collaboration with film-maker Brady Haran, we developed the YouTube channel <i>Sixty Symbols</i> which presents research in physics to the public. Since its launch we have released 354 videos (137 over the REF2021 assessment period), with the channel amassing 534k new subscribers, 119k comments, and more than 67.1M views worldwide since August 2013. This has led to impact on society, culture and creativity through the promotion of public engagement and discourse on science and engineering, educational use, and career impact. In 2019, to facilitate the use of the videos in schools, we created <i>Sixty Ideas</i>, an online resource for teachers with a special collection of videos linked to the UK A-level syllabi. Quantitative evidence gathered by <i>Linguistic Profiling for Professionals</i> demonstrates <i>Sixty Symbols'</i> global reach, and significant impact on the attitudes, scientific understanding and career aspirations of its audience in all age groups.</p>		
2. Underpinning research		
<p>We established <i>Sixty Symbols</i> in 2009 to disseminate our research using social media, specifically YouTube videos. In many videos, researchers discuss the principal results, context and significance of a particular research paper on which they were a co-author. To complement the focus on specific research outputs, many other videos were produced in which researchers from a particular sub-discipline provide a critical discussion and/or background explanation of contemporary physics research, scientific curiosities, science in current affairs, discoveries highlighted in the media, and notable international scientific achievements (for example the award of Nobel prizes). In all cases the videos derive their authority from the expertise of the featured researchers. Accordingly, the presenters provide a link between the video content and both our specific research papers, and the body of research expertise within the School of Physics and Astronomy.</p> <p>Initially, the videos were themed around 60 physics symbols but, following the success of this initiative, this was expanded to encompass a wide range of topics in fundamental and applied physics in videos delivered by 17 of our academic staff, as well as postdoctoral research assistants and PhD students. To highlight the role of physics across a wide range of scientific ideas and disciplines, we have produced videos based on all research areas within the School, encompassing biomedical imaging, particle theory, cosmology, astronomy, theoretical physics, nanoscience and condensed matter physics. Some examples of our research presented in the <i>Sixty Symbols</i> videos are outlined below.</p> <p>Astronomy: Videos by <i>Merrifield</i>, <i>Gray</i> and <i>Almaini</i> outline concepts of research on galactic astronomy and the formation and evolution of galaxies [i] such as 'Hydrogen Alpha', 2015 (deep-red visible emission-line) [1], 'What are black holes?', 2016 (looking at Active Galactic Nuclei feedback), 'Redshift', 2009 (surveys of the distant Universe), 'Dark Matter', 2010 (the</p>		

existence and distribution of dark matter in the Universe) and a number of videos on the companion [Deep Sky Videos](#) channel that focuses on astronomy (see **Section 4**).

Experimental Condensed Matter and Nanoscience: A series of nanoscience videos by *Moriarty* describe research on imaging, spectroscopy, and manipulation down to the single chemical bond level using dynamic force microscopy under ultrahigh vacuum conditions and cryogenic temperatures [ii], e.g. '[The sound of atoms bonding](#)', 2014 on mapping the force field of a hydrogen-bonded assembly [2]. Videos on magnetic levitation including the two-sphere swimmer experiment and theory '[Little Swimmers](#)', 2015 by *Hill* [3], on magnetotunnelling spectroscopy of graphene's Dirac Fermions [4, iii] '[Left-handed Electrons](#)' 2015 by *Eaves* [I] and his accompanying video on [Computerphile](#) comparing silicon and graphene-family FETs [5], and forensic footwear '[Footwear Forensics](#)' 2016 by *Sharp* [6].

Particle Cosmology: Videos presented by *Padilla*, *Copeland* and *Burrage* [II] relate to particle cosmology including '[Cosmological Constant & The End of the Universe](#)', 2014 [7], '[Primordial Black Holes](#)' 2014 [iv], and the link between dark matter and supersymmetry in '[Shining Light Through Walls](#)' 2015 and '[Chameleon Particles and Dark Energy](#)' 2015 [8,v] as well as videos on the [Numberphile](#) sister channel.

3. References to the research

Publications: BOLD indicates UoN academic staff who delivered associated video

[1] Chies-Santos, A. L., Rodríguez del Pino, B., [...] **Gray, M E.**, et al, OMEGA - OSIRIS Mapping of Emission-line Galaxies in A901/2 - I. *Monthly Notices of the Royal Astronomical Society* **450**, 4458–4474, 2015. DOI: 10.1093/mnras/stv779.

[2] Sweetman, A. M., Jarvis, S. P., [...], **Moriarty P.**, Mapping the force field of a hydrogen-bonded assembly, *Nat. Commun.* **5**, 3931, 2014. DOI: 10.1038/ncomms4931.

[3] Klotsa, D., Baldwin, K., **Hill, R.J.**, Bowley, R.M., Swift, M.R., Propulsion of a Two-Sphere Swimmer, *Phys. Rev. Lett.* **115**, 248102, 2015. DOI: 10.1103/PhysRevLett.115.248102.

[4] Greenaway, M.T., [...], Fromhold, T.M., **Eaves., L.**, Resonant tunnelling between the chiral Landau states of twisted graphene lattices, *Nature Physics* **11**, 1057–1062, 2015. DOI: 10.1038/nphys3507.

[5] Bandurin, D.A., [...], Patanè, A., **Eaves, L.**, [...], Geim, A.K., Cao, Y., High electron mobility, quantum Hall effect and anomalous optical response in atomically thin InSe, *Nat. Nanotechnol.* **12**, 223-227, 2017. DOI: 10.1038/nnano.2016.242.

[6] Needham, J. A., **Sharp, J. S.**, Watch your step! A frustrated total internal reflection approach to forensic footwear imaging, *Sci. Rep.* **6**, 21290, 2016. DOI: 10.1038/srep21290.

[7] Kaloper, N., **Padilla A.**, Sequestering the Standard Model Vacuum Energy, *Phys. Rev. Lett.* **112**, 091304, 2014. DOI: 10.1103/PhysRevLett.112.091304.

[8] **Burrage, C.**, Sakstein J., A compendium of chameleon constraints, *J. Cosmol. and Astropart. Physics* **11**, 045, 2016. DOI: 10.1088/1475-7516/2016/11/045.

Grants:

[i] 'Astronomy & Astrophysics at Nottingham', PI: Almaini, O., STFC ST/L000695/1, (Apr 2014 – Mar 2017), GBP804,113.

[ii] 'Digital Matter: towards mechanised mechanosynthesis', PI: Moriarty, P., EPSRC Leadership Fellowship EP/G007837/1, (Nov 2008 – Mar 2014), GBP1.7 M.

[iii] 'EU FP7 Graphene Flagship Project' PI: Patanè, European Commission 604391, (Oct 2014 – Mar 2016), GBP123,048.

[iv] 'The Cosmology of the Early and Late Universe', PI: Padilla, A., STFC STF/J000388/1, (Oct 2011- Sept 2014), GBP442,000.

[v] 'Dark Energy: Preparing Theory to Meet Experiment', PI: Burrage, C., Royal Society Research Fellowship UF110186, (Jan 2013 - 2018), GBP520,000.

[vi] 'Sixty Symbols Ogden Trust Fellow', PI: Smethurst, B., (Feb 2017 – Sept 2018).

[vii] 'Curating Sixty Symbols: Connecting Teachers with Content', PI: Gray, M., Hermes Fellowship Programme, University of Nottingham, (Sept 2017 – July 2018), GBP4,200.

Prizes and Recognition for members of the Sixty Symbols team:

[I] Professor Laurence Eaves, Institute of Physics (IoP) Nevill Mott Medal and Prize (2020) 'for his outstanding contributions to the investigations of fundamental electronic properties of quantum-confined systems and their applications in devices.'

[II] Professor Clare Burrage, Institute of Physics (IoP) Maxwell Medal and Prize (2015) 'for her contributions to dark energy research, in particular the development of methods of testing for fifth forces from astrophysical probes through to atom interferometry'.

[III] Brady Haran, Professor Michael Merrifield and Professor Philip Moriarty, Institute of Physics (IoP) Kelvin Medal (2016) 'for innovative and effective promotion of the public understanding of physics through the Sixty Symbols video project'.

4. Details of the impact that has occurred

The *Sixty Symbols* project (<http://www.sixtysymbols.com>) arose from interest within the School in providing a route to engage wide and diverse audiences with research concepts and scientific ideas in physics using new forms of social media and mobile technology, and to reach a much wider audience, both demographically and geographically, than is possible using conventional approaches to outreach. Our collaborator, Brady Haran, an ex-BBC freelance journalist, had previously worked with the School of Chemistry (UoN) to produce short videos; a shared aim was for *Sixty Symbols* to provide viewers with the sense of membership of an online community through the use of themes, familiar faces, and a common informal presentational style [a].

Since its launch, 354 *Sixty Symbols* videos have been posted (137 in REF2021 assessment period). The success in creating a community is evident from the rapid growth in the number of *Sixty Symbols*' subscribers, with 534k new subscribers, 119k comments, and more than 67.1 M views during the REF2021 assessment period (see Table 1). There is a high proportion of return viewers, demonstrated by large numbers of below-the-line video comments [a].

Viewing statistics for *Sixty Symbols* compare very favourably with other acclaimed science research communication YouTube channels. Table 2 shows a comparison of subscriber numbers and views/annum for channels launched by the Institute of Physics, CERN, Nature and Scientific American; statistics confirm the scale and reach of *Sixty Symbols*, in particular the

favourable comparison with the YouTube channel of Nature, one of the leading scientific publishers. *Sixty Symbols* is widely regarded as "one of the most successful series of scientific videos", as stated in 'Phys FilmMakers: teaching science students how to make YouTube-style videos' (*Eur J Phys*, Vol. 39, 015706, 2018).

Thirty *Sixty Symbols* videos link to specific research papers; of these nineteen were published in the REF2021 assessment period amassing combined views of 4.8 M. These videos are: '[How loud was the Big Bang?](#)' (viewing figures 103,000), '[The uncertainty principle and waves](#)' (126,000), '[Anatomy of a Physics Experiment](#)' (102,000), '[Black Holes](#)' (366,000), '[Footwear Forensics](#)' (68,000), '[The Black Hole Machine](#)' (217,000), '[What are Black Holes?](#)' (227,000), '[Chameleon Particles and Dark Energy](#)' (110,000), '[A Drumming Experiment](#)' (107,000), '[Hydrogen Alpha](#)' (186,000), '[Cosmological Constant & The End of the Universe](#)' (271,000), '[Do Atoms Ever Touch?](#)' (535,000), '[Primordial Black Holes](#)' (251,000), '[The Sound of Atoms Bonding](#)' (279,000), '[World's Smallest Christmas Tree](#)' (157,000), '[Cosmic Superstrings](#)' (616,000), '[Little Swimmers](#)' (89,000), '[Left Handed Electrons](#)' (200,000), '[Shining Light Through Walls](#)' (142,728).

Those published prior to August 2013 continued to amass viewing figures during the REF2021 assessment period: '[Physics of Moshing](#)' (142,000), '[Atomic Switch](#)' (89,000), '[Gold Nanoparticle](#)' (204,000), '[Granular Dynamics](#)' (189,000), '[Dark Matter](#)' (429,000),

Table 1: Summary Statistics on Sixty Symbols

Figures since launch in 2009:	
Videos published	354
Views	88.3M
Subscribers	812k
Below-the-line comments	317k
Figures over REF2021 assessment period:	
Videos published	137
Views	67.1M
New subscribers	534k
Below-the-line comments	119k

Table 2: Comparison with leading Science YouTube Channels

Channel	Launch	Views/annum since launch	Subscribers
Sixty Symbols	2009	7.6M	819k
Nature	2008	6.8M	510k
CERN	2008	0.6M	128k
IOP	2007	0.6M	30.8k
Scientific American	2008	2.4M	229k

'[Foam Physics](#)' (165,000), '[Redshift](#)' (121,000), '[Spiral galaxies](#)' (129,000), '[Magnetic field](#)' (119,000), '[Beer levitation](#)' (129,000), '[Weird surface tension](#)' (223,000) [a].

In 2017, *Sixty Symbols* received funding from the Ogden Trust [vi] for a post-doctoral *Sixty Symbols* Fellow (Dr Becky Smethurst) to generate new videos and provide an insight into the early career of a research scientist, with video outputs including '[Forcing Weapons from Neutron Stars](#)' (146,622), '[James Webb Space Telescope](#)' (237,798), and '[the Age of the Universe](#)' (181,964). Dr Becky Smethurst has since gone on to launch her own YouTube channel ('[Dr. Becky](#)'), and book 'Space: 10 Things You Should Know'. She commented that '*without the opportunity provided to me by the *Sixty Symbols* Research Fellowship to pursue both independent research and communicate physics to a wide audience, I would not have been able to achieve the same level of success in my career*' [b]. Further, *Sixty Symbols*' success has led to the launch of spin-off channels and to invitations to researchers in the School to present videos on physics research for these other YouTube channels, namely [Deep Sky Videos](#) related to astronomy research, [Numberphile](#) related to mathematics and [Computerphile](#) related to computer science. Filmmaker Haran comments '*The success of the format has been underlined by the funding that we've received for further spin-off channels, such as the support from Google to help set up the *Deep Sky Videos* companion astronomy channel, and the grant won from the STFC to create a suite of videos highlighting their work. I was particularly pleased when the influence of this work was recognised by the Institute of Physics, through the award of the 2016 Kelvin Medal to me and colleagues from the University.*' [c]. IoP President, Professor Sambles, states of the Kelvin Medal: '*The recipients represent some of the best and brightest minds involved with physics in academic and industrial research, in education and in outreach. These awards recognise their outstanding contribution to the development of their own fields of interest and also their ongoing commitment to strengthening the reputation of UK physics.*'

Sixty Symbols led to Professor Moriarty publishing a popular non-fiction book '*When the Uncertainty Principle Goes to 11: Or How to Explain Quantum Physics with Heavy Metal*' published 16 August 2018, which was shortlisted for *Physics World's Book of the Year 2018* [e, Acknowledgement on page 329]. *Sixty Symbols* has been presented widely, including at the [Bluedot Festival](#) in 2018.

Sixty Symbols is listed as a teaching resource across a number of websites (for example, tes.com and schoolsience.co.uk) [f]. To further facilitate the use of *Sixty Symbols* videos in schools, in **August 2019** we launched *Sixty Ideas* (<https://www.nottingham.ac.uk/physics/sixtyideas/index.aspx>), an online resource for teachers with a curated collection of videos [vii] aligned to the UK A-level syllabi. This resource was promoted at the Association for Science Education (ASE) Annual Conference in January 2020, Europe's Largest Science Education Conference. A Secondary School Physics Teacher comments that '*The videos have been great for giving the students a breadth of knowledge beyond what is in the textbook - they really engage with them and they've led to some very interesting conversations.*' [g].

To assess the impact of *Sixty Symbols*, a report was commissioned by Linguistic Profiling for Professionals in **2020** [a]. This demonstrates the changes in the REF2021 assessment period that *Sixty Symbols* has brought to individuals, the University of Nottingham and wider society. Comments made on the videos directly linking to research were examined using corpus linguistics techniques with specialist computer software to scrutinise large collections of computer-readable texts. The report details viewing figures and highlights:

- The word 'love' was in the top ten collocates and superlatives elevating *Sixty Symbols*.
- There is ample evidence of below-the-line comments that demonstrate *Sixty Symbols* has increased the public's access to physics, and those who self-identify as having no background or formal education in physics actively engage.



Linguistic Profiling for Professionals Keywords word cloud, [a, page 3]

- There is a significant body of comments in which users directly refer to the videos having assisted or enhanced their understanding of a Physics topic.

Impact on people's lives is evident from the comments:

- *'One of the best channels anywhere on the internet. Consistently jaw-dropping, accessible science.'* (Granular Dynamics, comment 261)
- *'Your videos are extremely inspiring even to laymen like myself. The love and passion all professors have for your subjects and science and wanting to talk and discuss and put it out there for us is remarkable.'* (World's Smallest Christmas Tree, comment 165)
- *'Fantastically clear explanation of this telescope and how filters work. I wish I had an instructor like Dr Gray for every subject I had in school!'* (Hydrogen Alpha, comment 18)
- *'Thanks to the brilliant explanation of the Doctor, This is the first time I have understood what uncertainty principle really is'* (The Sound of Atoms Bonding, comment 353)
- *'a great discussion! REALLY makes you think!'* (Do Atoms Ever Touch, comment 791)

Further, there is clear evidence from email correspondence that the channel engages groups that are currently underrepresented in STEM subjects, particularly women and girls, by providing a platform for female scientists who inspire women to study these subjects [a]. Geographical analysis of viewer statistics shows that the channel has a wide international reach, with evidence of viewers in, at a minimum, Europe (e.g. Belgium, France, Germany, Russia, Spain and Switzerland), North America (e.g. Canada, Mexico and USA), South America (Brazil), East (China, Japan) and South Asia (India), and New Zealand.

An online survey completed in 2019 by current physics students at the University of Nottingham explored the influence that *Sixty Symbols* has had over individuals both before they enrolled in university and while studying there [h]. Three-quarters of respondents reported their experience of *Sixty Symbols* as having had a positive influence on their interest and understanding of physics and their choice of Nottingham as their place to study.

Comments and critical reviews by leading scientific communicators are highly positive:

Brian Cox (physicist and science communicator): [i] *'science content on-line is now one of the primary ways that research is disseminated to the public, and will become the most important platform for outreach, eclipsing more traditional broadcast media in terms of reach and influence. Sixty Symbols is now a well-established and influential brand in this rapidly expanding space. The subjects covered are often directly related to research at Nottingham and provides a platform for many academics to discuss their work. [...] its 347 videos (at the time of writing) have had in excess of 86 M views. To put that in context, a successful BBC One 'landmark' science program today would be considered a tremendous success with a live and on-line audience of 4-6 M. I would therefore classify Sixty Symbols as having had a high impact in presenting the research at Nottingham to a very large audience.'*

Simon Singh (science writer): [j] *'After many years of success, Sixty Symbols continues to be an excellent example of science engagement. [...] Without doubt – and I have looked at dozens (hundreds?) of outreach projects over the last 20 years – Sixty Symbols is one of the best projects I have encountered. [...] interesting, fun and challenging videos that build a connection between the academics and various audiences, from young kids to adults.'*

5. Sources to corroborate the impact that has occurred:

[a] Linguistic Profiling for Professionals (LiPP): *Sixty Symbols* Public Engagement REF Case Study: A Linguistics Analysis, September 2020.

[b] Letter from Becky Smethurst to Michael Merrifield, October 2019.

[c] Letter from Brady Haran to Michael Merrifield, November 2019.

[d] List of *Sixty Symbols* awards.

[e] Professor Philip Moriarty book 'When the Uncertainty Principle Goes to 11: Or How to Explain Quantum Physics with Heavy Metal' published 16 August 2018.

[f] List of teaching resource websites.

[g] Letter from Secondary School Teacher Dr Farmer to Meghan Gray, August 2020.

[h] School of Physics, University of Nottingham Students' Survey Findings, March 2019.

[i] Letter from independent physicist/science communicator Brian Cox, September 2020.

[j] Letter from independent science write Simon Singh to Mike Merrifield, March 2020.