Institution: University of Exeter

Unit of Assessment: Physics

Title of case study: Inspiring the next generation of Physicists through engagement

1. Summary of the impact (indicative maximum 100 words)

A public engagement campaign based around 15 years of natural photonics research at Exeter University succeeded in enthusing school-age children in a science that was suffering declining levels of interest. Professor Pete Vukusic gave a series of lectures that brought the science of light and colour to life for 17,000 students and 1,500 teachers across the UK, Ireland and Africa, and subsequently a global audience of thousands via YouTube. His work played a central role in the Institute of Physics' efforts to promote the value of physics in the UK and overseas, contributing to a marked rise in the number of students taking physics A-level. In 2013, Vukusic was awarded the distinguished Royal Society Kohn Award for Excellence in Engaging the Public with Science.

2. Underpinning research (indicative maximum 500 words)

Physics-based businesses contribute 8.5% of the UK's economic output and employ more than one million people, according to the Institute of Physics (IOP). However in recent years the supply of highly skilled physics graduates to support innovation in the sector has come under pressure. Declining popularity of physics among A-level students was highlighted in 2006 when research revealed that A-level entries fell from 55,728 in 1982 to 27,368 in 2006.

It was against this backdrop that Professor Pete Vukusic (joined Exeter in 1998) was co-leading research into natural photonics at the University of Exeter, following a career as a secondary school science teacher. Working closely with Roy Sambles, Professor of Experimental Physics, he investigated the mechanisms by which some of the brightest and most vivid iridescent colours in nature are produced as a result of the interaction of light with micro- and nano-scale periodic structured surfaces [3.1 - 3.6]. These structures occur in the wings of butterflies, hummingbirds and a diversity of animals, where a combination of multilayer interference and optical gratings gives rise to a broad array of colour appearances through ultra-high reflectance, coherent scattering and (often) narrow-band spectral purity. Vukusic's analyses of many 'living jewel' systems, many published in *Nature* and *Science* journals, revealed how often unusual periodic and quasi-periodic microstructure can produce bright iridescence [3.1 - 3.6]. A *Science* paper in 2005 showed how the naturally evolved light extraction system on the wing scales of a *Papilio* butterfly could be applied to the development of a high efficiency LED [3.2]. A later paper in *Science,* in 2007 [3.3], elaborated on how photonic structures within beetle elytra are providing inspiration for innovative technological applications.

There are a wealth of complex biological structural designs and optical effects that mirror many technological photonic system designs. The physics and morphology of these structures are well understood [3.4]; however, how to replicate these optical structures for commercial use, such as in cosmetics and anti-counterfeiting technologies, is less clear. Because of this, more recently Vukusic's research has focussed on mimicking and fabricating bio-inspired structures using a combination of layer deposition techniques, including colloidal self-assembly, sol-gel techniques, sputtering and atomic layer deposition [3.5]. Vukusic has applied his understanding of natural photonics to the development of a range of technologies. In 2013 [3.6], he published a paper announcing the invention of a new fibre that changes colour when stretched. The design principles were based on the replication of the unique structural elements that create the bright iridescent blue colour of a tropical plant's fruit.

This body of research, through its exploration of colour and light, was a natural fit for a public engagement campaign aimed at stimulating interest in physics among children and young adults. In 2007, Vukusic was selected by the IOP to give its funded series of schools lectures. He

delivered *Light Fantastic: The Science of Colour* in an effort to educate and enthuse students with the wonders of light and colour, based entirely on his research activity. In 2007, 85 IOP-sponsored lectures at 55 venues across the UK were delivered to audiences of 14-16 year olds, with Vukusic drawing on his experience both as a natural photonics research scientist and a schoolteacher to deliver a series of dynamic outreach lectures, demonstrations and workshops.

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

References in bold best indicate the quality of the underpinning research.

3.1. "Photonic structures in biology", P. Vukusic and J. R. Sambles, Nature **424**, 852-855 (2003).

3.2. "Biomaterials: Directionally controlled flourescence emission in butterflies", P. Vukusic and I. R. Hooper, Science 310, 1151 (2005).

3.3. "Brilliant whiteness in ultrathin beetle scales**", P. Vukusic, B. Hallam, and J. Noyes, Science 315, 348 (2007).**

3.4. "Evolutionary photonics with a twist", P. Vukusic, Science, **325**, 398 (2009).

3.5. "Mimicking the colourful wing scale structure of the Papilio blumei butterfly**", M. Kolle, P. M. Salgard-Cunha, M. R. Scherer, F. Huang F, P. Vukusic, S. Mahajan, J. J. Baumberg, and U. Steiner Nat. Nanotechnol. 5, 511 (2010).**

3.6. "Bio-inspired band-gap tunable elastic optical multilayer fibers", M. Kolle, A. Lethbridge, M. Kreysing, J. J. Baumberg, J. Aizenberg and P. Vukusic, Adv. Mater. **25**, 2239 (2013).

Grants

3.7. "Bio-inspired Photonics", DARPA/GE Global DARPA-BAA 09-71 extension (PI P. Vukusic, $49,045, Jan – Dec 2012).

3.8. "Bio-inspired Photonics", DARPA DARPA-BAA 09-71 (PI P. Vukusic, £51,440, Jan 2010 - July 2011).

3.9. "BioOptics", USAF Multi-University Research Initiative (MURI), FA9550-10-1-0020, (PI P. Vukusic, $1.2M, July 2009 – June 2014).

3.10. Funds to support travel, equipment and expenses relating to the IoP UK Schools' Lecturership, Institute of Physics (PI P. Vukusic, £21,000, Jan 2007-2008).

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

In recent years, the uptake of physics at A-level has experienced a resurgence. From a low of 27,368 in 2006, the number of A-level entries climbed to 32,860 in 2011. Figures from UCAS revealed an approximately 2,000 increase in students applying for physics courses at UK universities between 2011 and 2012. This 8.3% rise is at odds with an overall 8.7% decline in university applicants across the UK. While it is impossible to measure the individual contribution of Vukusic's public engagement campaigns – based wholly on 15 years of his research into natural photonics – to this popularity upswing, his outreach activities have formed a significant part of the UK physics community's wider successful efforts to capture the public imagination, which in turn has extended the reach of Vukusic's activities to Ireland and Africa.

Building on the schools tour in 2007, Vukusic initiated subsequent tours of the *Light Fantastic: The Science of Colour* lectures for young people [5.1]: between 2008 and 2013 he gave 160 presentations (the majority in the UK) to primary and secondary schools. The lectures set out to elucidate the science behind light and colour to stimulate students' curiosity beyond the classroom, and were designed to complement the National Curriculum and its Scottish and Irish equivalents. The lectures featured the electromagnetic spectrum, how colour is produced when light interacts with structures, how structural colour is produced and used in nature**,** and how examples of natural structural colour are influencing new technology and products, from cosmetics to fashion.

The impact of the 2007 tour continued throughout the REF period. The IOP filmed Vukusic's original lecture and distributed 5,000 free DVDs to IOP-member schools. In January 2012, it was

uploaded to YouTube [5.2] and has been viewed over 17,000 times so far. The majority of viewers are from the USA, UK, Canada, Australia and India. The video was uploaded as a teaching resource on the TES UK and India websites in 2012 and 2013, where it is freely available for 2.5m registered online users in 274 countries.

Demonstrating the success of the lectures, Vukusic was awarded the British Association of Science Lord Kelvin Prize for science lecturing in 2008. He received repeat invitations from many schools, for example a lecture at Rugby School in January 2013 led to a request for him to return in June for the 25th anniversary of the IOP teachers' meeting. Following one lecture at The Westgate School in Slough, the Deputy Head wrote that Vukusic's talk had "completely changed a number of students' (many of whom had previously failed the 11+) feelings towards pursuing their studies at university level." [5.3].

In 2011, Vukusic, again funded by the IOP, took the lecture series to Ireland [5.4] where he reached more than 4,500 schoolchildren and 50 teachers through 11 lectures that tied in with the school curriculum. The tour was organised in response to declining numbers of Irish schoolchildren taking physics at Leaving Certificate level. Writing in the Irish Times in 2012, the Chair of the IOP in Ireland said that a quarter of schools were not offering the subject at Leaving Certificate level.

In May 2012, the IOP provided 'in kind' (stationery, textbooks, DVDs) and logistical support to enable Vukusic to take his lecture series to Africa. This contributed to the IOP's international programme, which seeks to advance physics in the developing world for economic and social benefit. Vukusic arranged lectures at five schools in the poorest parts of the Ethiopian capital Addis-Adaba, reaching more than 1100 students and 15 teachers [5.5, 5.6]. The Director of the Addis-Ababa Education Bureau said: *'…surprisingly enough, social science students who took part in your public lecture have insisted to be members of the science and technology club to whom we have accepted their appeal* [5.6]." Vukusic took the lecture tour to Tanzania and on to Malawi, where he visited eight rural schools over four days, reaching 1,500 pupils and 55 teachers. This trip was part-funded by Ripple Africa, a charity that works to improve quality of education. The charity's programme lead said Vukusic was "an inspiration" to the students, commenting that the lectures complemented the Malawian science syllabus. He asked Vukusic to return every year [5.7].

Vukusic's lectures have also engaged adult audiences. He exhibited his photonics research at the Royal Society Summer Exhibition in 2011 and, since 2008, has given talks at five major science festivals, including a Royal Society event in Tokyo in 2008 and the Dublin Science Festival in 2009. He has given talks to 37 clubs and societies and media appearances since 2008 include BBC Radio 2 *Drivetime* with Chris Evans, *Material World* on BBC Radio 4 and National Geographic News.

In July 2013, Vukusic was awarded the distinguished Royal Society Kohn Award for excellence in engaging the public with Science [5.8].

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

5.1. Letter 25/04/2013 Science Enrichment Coordinator, La Sainte Union Secondary School.
5.2. IOP Youtube video: http://youtu.be/TWhGmwUojBE
5.3. Letter 05/02/2013 Deputy Head Teacher, Westgate School
5.4. Irish Teachers Association, Institute of Physics Lectures http://www.ista.ie/news/institute-physics
5.5. Letter 25/05/12 Director Dejazmach Preparatory School
5.6. Letter 25/05/12 Deputy Director Addis-Abab City Education Bureau.
5.7. Letter 11/12 Education Authority, Ripple Africa Charity, Malawi.
5.8. Royal Society Kohn Award for Excellence in Engaging the Public with Science, July 2013.