Institution: Nottingham Trent University

Unit of Assessment: B15 General Engineering

Title of case study: Public Understanding: Nature's Raincoats

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

Nature's Raincoats is a physical exhibition and a website providing easily accessible information and resources. These entities have had extensive use within the public understanding of superhydrophobic surfaces (extremely repellent to water), including The Royal Society Summer Science Exhibition, Cheltenham Science Festival, The Big Bang Fair, British Science Festival and Techfest (India) - reaching thousands of people in the UK and overseas. As well as impacting on improved public awareness, the research informed website provides a direct route to research expertise for companies within the UK and internationally and extends good practice of working with industry e.g. Rolls Royce.

2. Underpinning research (indicative maximum 500 words)

The research elucidates how the use of micro- and nano-topography can amplify surface wetting properties beyond that achievable simply though surface chemistry. Properties achieved include super water repellency (superhydrophobicity), often referred to as the "Lotus Effect", and super wetting. NTU researchers were one of the earliest UK groups to work in this field, since 1999, and remain active today. The research is underpinned by 9 EPSRC awards since 2001, including an EPSRC Platform grant [EP/E063489/1] recognising the world-leading quality.

The work is wide-ranging in its breadth of relevance across science and engineering with 6 example references provided in section 3 from more than 30 journal articles in the field.

Initial materials methods research showed how superhydrophobicity could be intrinsically built into foams with surface properties renewed by abrasion [1]. Further original research showed how lithographic, electro-deposition, etching and other techniques could produce these properties, e.g. ref. [2] underpinned by grant [GR/R02184/01].

Ref. [3], a review article referring to the group's original research, is the most cited article ever published in the leading journal Soft Matter (490 times @ 25/09/13). With our original research papers, it established the group as a world-leading source of expertise on materials methods in this area.

Research developed from materials methods into applications of superhydrophobicity. For example, the group demonstrated sensor responses using switching concepts (e.g. [4] cited in Nature News 2005, grant [GR/S34168/01], and subsequent articles).

We then established that superhydrophobic concepts within natural systems could explain extreme water repellence arising from forest fires and use of grey water for irrigation. For example, see [5] and related articles in European Journal of Soil Science, Applied Physics Letters, Hydrological Processes underpinned by grant [EP/C509161/1] in collaborations with Geographers in Swansea. Ref [6] is an exemplar of published research on using immersed superhydrophobic surfaces for underwater respiration, what insect physiologists call a "plastron", without the need for a gill. The group also demonstrated how lichens use a similar natural "Gore-Tex" type membrane to buffer water and for plants to collect water using passive methods; this led to collaborations with Biologists in Kleve (Germany).

The ability of such nano- and micro-structured surfaces to reduce solid-liquid contact area and to create a surface retained layer of air also became of interest in methods of drag reduction (grant [EP/D500826/1]) both within lab-on-a-chip systems and surfaces used in sailing. This led to collaborations with computational fluid dynamics and marine engineers in Southampton (grant

[EP/G057265/01]) and UK Sport as an invited project of the UK Sport-EPSRC Olympics initiative in Team GB preparations for the 2012 Olympics (grant [EP/E043097/1]).

The significance of the group's original research output and recognition for world-leading expertise is evidenced by a range of invited highlight, emerging area, comment and review articles for journals including, Analyst (2004), Nature Materials (2007), Soft Matter (2008), Langmuir (2009), Soft Matter (2010), Advances In Colloid and Interface Science (2010), Soft Matter (2011) and the Journal of Polymer Science B: Polymer Phys. (2011).

Key researchers & Staff Development: Prof. G. McHale (Lect 1990, Prof 2002-2012); Prof. C.C. Perry (Lect 1993, Prof 2002-present); Dr. M.I. Newton (Lect 1988, Reader 2001-present); Dr. N. Shirtcliffe (Senior Research Fellow 2001, now Assoc. Prof. of Bionics & Biomimetic Materials at Rhein-Waal University of Applied Sciences); Dr. P. Roach (Ph.D. Researcher 2002, now Lecturer in Biomedical/Cell Engineering at Keele University).

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

References to key outputs from the research

The group have published over 120 Journal articles and 17 book chapters since 1993.

Three references indicating the quality of the underpinning research

[1] Authors: Shirtcliffe, NJ; McHale, G; Newton, MI; Perry, CC; Title: Intrinsically superhydrophobic organosilica sol-gel foams; Year: (2003); Journal Title: LANGMUIR; Vol. 19 p5626; DOI http://dx.doi.org/10.1021/la034204f
[2] Authors: Shirtcliffe, NJ; McHale, G; Newton, MI; Chabrol, G; Perry, CC; Title: Dual-scale roughness produces unusually water-repellent surfaces; Year: (2004); Journal Title: ADVANCED MATERIALS; Vol. 16 p1929; DOI http://dx.doi.org/10.1002/adma.200400315
[3] Authors: Roach, Paul; Shirtcliffe, Neil J.; Newton, Michael I.; Title: Progess in superhydrophobic surface development; Year: (2008); Journal Title: SOFT MATTER; Vol. 4 p224; DOI http://dx.doi.org/10.1039/b712575p

Three additional references indicating the quality of the underpinning research

[4] Authors: Shirtcliffe, NJ; Mchale, G; Newton, MI; Perry, CC; Roach, P; Title: Porous materials show superhydrophobic to superhydrophilic switching; Year: (2005); Journal Title: CHEMICAL COMMUNICATIONS; Issue 4 p3135; DOI http://dx.doi.org/10.1039/b502896e
[5] Authors: Hamlett, Christopher A. E.; Shirtcliffe, Neil J.; McHale, Glen; Ahn, Sujung; Bryant, Robert; Doerr, Stefan H.; Newton, Michael I.; Title: Effect of Particle Size on Droplet Infiltration into Hydrophobic Porous Media As a Model of Water Repellent Soil; Year: (2011); Journal Title: ENVIRONMENTAL SCIENCE & TECHNOLOGY; Vol. 45 p9666; DOI http://dx.doi.org/10.1021/es202319a
[6] Authors: Shirtcliffe, Neil J.; McHale, Glen; Newton, Michael I.; Perry, Carole C.; Pyatt, F. Brian; Title: Plastron properties of a superhydrophobic surface; Year: (2006); Journal Title: APPLIED PHYSICS LETTERS; Vol. 89 p104600; DOI http://dx.doi.org/10.1063/1.2347266

Evidence of the quality of the research: Key Research Grants

- Recipient: G. McHale, M.I. Newton & C.C. Perry; Grant title: Superhydrophobic and superhydrophilic surfaces; Sponsor: EPSRC GR/R02184/01 and MOD/Dstl Joint Grant Scheme; Award period dates: 2001-2004; Grant value: £183 238.
- Recipient: G. McHale & M.I. Newton; Grant title: Voltage switchable superhydrophobicity; Sponsor: EPSRC GR/S34168/01; Award period dates: 2004-2007; Grant value: £195,141.
- Recipient: F.B. Pyatt, G. McHale & M.I. Newton; Grant title: Extreme soil water repellency; Sponsor: EPSRC EP/C509161/1; Award period dates: 2004-2005; Grant value: £63,009.
- Recipient: G. McHale, M.I. Newton & C.C. Perry; Grant title: Drag reduction and slip at solid-liquid interfaces; Sponsor: EPSRC EP/D500826/1; Award period dates: 2005-2009; Grant value: £205,498.
- Recipient: G. McHale, M.I. Newton, C.C. Perry & N.J. Shirtcliffe; Grant title: Olympics Pilot

Project - Enhancing Water Sports Performance ; Sponsor: EPSRC-UK Sport EP/E043097/1; Award period dates: 2007-2008; Grant value: £110,369.

- Recipient: G. McHale, M.I. Newton & C.V. Brown; Grant title: Platform Grant - Exploiting the solid-liquid interface; Sponsor: EP/E063489/1; Award period dates: 2007-2012; Grant value: £643,981.
- Recipient: G. McHale & M.I. Newton; Grant title: Engineering of surfaces for drag reduction in water with validation using computational and experimental methods; Sponsor: EPSRC EP/G057265/01; Award period dates: 2009-2013; Grant value: £364,692.
- Recipient: G. McHale, M.I. Newton & N.J. Shirtcliffe; Grant title: Particle-based superhydrophobic surfaces: Lab models-to-field sample behaviour; Sponsor: EPSRC EP/H000704/1; Award period dates: 2009-2014; Grant value: £324,170.
- Recipient: G. McHale, P. Breedon, P. Johnson, M.I. Newton, T. Dias, T. Fisher, W.M. Cranton; Grant title: Smart Materials - Designing for Functionality; Sponsor: EPSRC EP/I016414/1; Award period dates: 2010-2012; Grant value: £202,311.
- Recipient: G. McHale (EP/K014803/1), C.V. Brown and M.I. Newton (EP/K015192/1); Grant title: Dielectrowetting: Controlling Oleo- and Hydrophilicity and Shaping Liquid Surfaces; Sponsor: EPSRC; Award period dates: 2013-2016; Grant value: £280k/£79.5k; Project partners: Dolomite Ltd, L-3 TRL Technology, Merck Speciality Chemicals Ltd

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

The development of the Nature's Raincoats initiative was a natural culmination of a growth in external interest of the research of the group.

During 2005-2007 the group received increasing numbers of enquiries from companies and the media relating to its research. Some related to a Nature Highlight/News which was heavily reported in the popular and trade press. Some related to an invited report for the Analyst aimed at industry practitioners, which contextualized our research in terms of existing patents and future possibilities. Some related to a New Scientist report "Repulsive vegetables". When the group published its research on underwater breathing without a gill the media interest included FoxNews.com, TechDigest and SoftPedia. This led to local newspaper and BBC radio interviews and eventually a 15-minute programme on BBC Radio 4 Material World.

In 2008, with the theoretical physics group of Professor Yeoman's at the University of Oxford, we decided to create a Public Understanding exhibit "Nature's Raincoats" at The Royal Society Summer Exhibition 2009. Ours was one of 21 selected from 103 proposals on the basis of scientific quality and novelty, and attractiveness in promoting Science to the general public, post-16 students, policy makers, and the press.

We created a website www.naturesraincoats.com with sections targeting general public understanding and companies wishing to understand more about how to work with us. We linked this into the Nottingham Science City initiative with the reporter Brady Haran who created www.test-tube.org.uk with a "Meet Neil Shirtcliffe" video, a "Superhydrophobic video" and a film about the Royal Society Exhibition. The exhibit was sponsored by EPSRC, the Materials KTN and included a photographic competition. The exhibition and web-site have been maintained by the group to create an enduring “front door” into the group's research. The exhibition is a series of hands-on exercises directly linked to our research (see www.naturesraincoats.com/Royal Society Exhibition.html).

1. Public understanding impacts through the Physical exhibition

The initial benefit of Nature's Raincoats was to the visitors to the Royal Society Exhibition, typically children inspired to continue science and engineering to a higher level. The exhibition had 5,522 visitors and worldwide media coverage.

The exhibition was invited (and sponsored) to appear at Techfest (Mumbai, India, in 2010 and 2012 www.techfest.org) - the largest Science and technology exhibition in India with an estimated 85,000 visitors. The exhibition was also invited (sponsored by EPSRC Public Understanding

Programme) to appear In the Discovery Zone at the 2010 Times Cheltenham Science Festival which sold about 23,000 tickets and was invited to appear at the National Big Bang Fair (www.thebigbangfair.co.uk) in London 2013 with 65,000 visitors followed by BBC Summer of UK wildlife event (Cardiff, June 2013) and the British Science Festival (Newcastle, September 2013, www.britishscienceassociation.org/british-science-festival).

2. Public understanding impacts through the Website and the Media

A second benefit was the general public understanding from the linked videos for the test-tube project e.g. [6] video explaining the basic science has had 260,823 visitors (@25/09/13). www.naturesraincoats.com had 21,020 unique visitors from July 2009 to May 2013 from over 40 countries with the largest being from the USA [7].

Media interest has also resulted in us providing a specially prepared laboratory coat (2009) for Richard Hammond's use in the series Invisible Worlds (BBC/Discovery Channel) and advice and guidance (2012) for the development of a stunt for use in the BBC series Richard Hammond's Miracles of Nature (Oxford Scientific Films) [3].

3. Commercial and Educational impacts

A third benefit was the raising of awareness of the commercial possibilities of the research through trade reports, for example, Eureka (a site for Engineering Design) "Nature shapes superior surfaces" 10/9/2009. More reports were made at the time, including for the Materials KTN, and permissions were granted for research images to be reproduced in an educational textbook.

Further benefits of the sustained website, YouTube videos and wider publicity have been to companies wishing to assess application of superhydrophobicity to their areas. Examples include: UK Sport, Water sports performance, EPSRC invited Olympics pilot project (see section 2) and separate project, 2008 [1]. Rolls Royce Plc (Derby, U.K.), 2008, leading to an in-house company programme and directly to the filing of two patents (US2011147219 and US2011151186) [2]. HumiSeal Europe Ltd. (Winnersh, U.K.), 2010, funded applied research on product development [5]. FurTech Ltd. (Glynneath, U.K.), 2011, product development pilot study [4].

In the US Troy Dassler, a teacher and outreach coordinator in Wisconsin, developed educational activities for children having used Natures Raincoats website and discussions with us resulting in an educational web site (http://microexplorers.blogspot.co.uk/2010/03/super-hydrophobic-surfaces.html) and with the work reported in an educational article "Recognizing Excellence: From Macro to Micro to Nano" [8].

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

1. Letter from Head of Research & Innovation, UK Sport, 40 Bernard Street, London, WC1N 1ST UK Sport (3 Nov 2011).
2. Letter from a specialist at Rolls Royce Plc Strategic Research Centre (SRC), PO Box 31, Derby, DE24 8BJ (11 Nov 2011).
3. Letter from a Researcher, Oxford Scientific Films, c/o Parthenon Entertainment, 34 Whiteladies Road, Clifton, Bristol BS8 2LG (21 Mar 2012).
4. Letter from FurTech Ltd., 40 Pontneathvaughan Road, Glynneath, W. Glamorgan SA11 5NS (11 Nov 2011).
5. Letter from the European Sales Manager, HumiSeal Europe Ltd, 505 Eskdale Road, Winnersh, Berkshire RG41 5TS (9 Nov 2011).
6. Youtube videos: http://www.youtube.com/watch?v=EaE9k-xUtrQ
7. Nature's Raincoats website: www.naturesraincoats.com and visitor statistics
8. Recognizing Excellence: From Macro to Micro to Nano, T Dassler *Science and Children* October 2011 http://learningcenter.nsta.org/product_detail.aspx?id=10.2505/4/sc11_049_02_69