Institution: Durham University		
Unit of Assessment: UoA 9: Physics		
Title of case study: P&G – Durham Physics Partnership		
Period when the underpinning research was undertaken: Between 2010 and 2019		
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:**
Prof John Girkin	Professor	2009 to present
Dr Halim Kusumaatmaja	Associate Professor	2013 to present
Prof Richard Bower	Professor	1995 to present
Period when the claimed impact occurred: Between August 2013 and December 2020		
Is this case study continued from a case study submitted in 2014? Y/N N		

1. Summary of the impact

A unique partnership between Durham University and Procter and Gamble (P&G) has enabled multiple industrially relevant research projects across experimental, computational and theoretical physics. These have led to new formulations and manufacturing processes for laundry detergents, the design of new liquid-repellent surfaces and improved testing of laundry and dishwasher products – exploited in P&G product lines such as “Tide”, “Ariel”, “Cascade” and “Fairy”. The partnership has won numerous awards and attracted inward investment of over GBP20million for the North East region. The estimated value of the improved P&G products and processes exceeds GBP800million per annum, in markets worth GBP11billion.

2. Underpinning research

The research underpinning the impact spans multiple groups within the Physics Department, including the Centre for Advanced Instrumentation (Girkin), the Centre for Materials Physics (Kusumaatmaja) and the Institute for Computational Cosmology (Bower). It was the breadth and interdisciplinarity of the research in the Physics Department that first attracted P&G to Durham University (*A Clean Solution*, Physics World, January 2013, by Michael Duncan, then-Global Director of Open Innovation for P&G, Professor Girkin and then-Durham Professor McLeish).

The research relationship between Durham Physics and P&G began with a project from P&G to improve grease removal in laundry at lower temperatures, and with smaller amounts of water. This minimises environmental damage as well as energy costs, but the process is difficult to study in detail as grease is optically active, leading to aberration of the images, and hence blurring, so that the effectiveness of different detergent formulations could not be resolved.

Professor Girkin is a world expert in adaptive optics (AO) and their applications to biological materials, such as mammalian brain tissues [R1] and zebrafish hearts [R2]. The core technique Professor Girkin pioneered for these studies is 3D optical microscopy, combining widefield and beam scanning imaging. Crucially, this can incorporate active elements, where the shapes of the optical surfaces are controlled in real time to compensate for aberration. Professor Girkin was able to develop “the world’s smallest washing machine” under a microscope with adaptive optics [R3], enabling visualisation of grease removal with different lipase formulations developed by P&G, at a scale never before seen. The resultant movies identified a new physical process which was important in the washing cycle, where bubbles of CO_2, released from the fat by the detergent, helped dislodge the grease from the surface.

The success of this programme led to further projects between P&G and Durham Physicists, developing similar optical instruments for measuring the cleanliness of dishwashed glasses.

A rather different project between P&G and Durham Physics focussed on developing new liquid-repellent surfaces. This was led by Dr Kusumaatmaja, a soft condensed matter physicist with expertise in wetting phenomena: how liquids interact with solid surfaces. Dr Kusumaatmaja's team has developed powerful computational approaches to study how equilibrium morphologies [R4] and dynamics of liquid droplets [R5] can be strongly influenced by surface roughness and structures. Using these in-silico research methods, Dr Kusumaatmaja has undertaken research with P&G's Transformative Platform Technology division in Cincinnati, to enable more efficient removal of soils, and to optimise the design parameters of superhydrophobic and liquid-infused surfaces.

Another collaboration was with Professor Bower, a computational cosmologist specialising in numerical simulations of the Universe. These are computationally very expensive and there are too many free parameters to explore the effect of each one. Instead, he developed Gaussian emulator methods in collaboration with statisticians in Mathematical Sciences, in order to reliably predict how the results depended on the control parameters with only sparse sampling of these parameters [R6]. This has widespread applications, and for P&G, the issue was how to optimise the spray drying process used to produce their laundry powders from wet slurries. Spray drying is energy intensive, so optimising it is important, both financially and environmentally. Professor Bower was able to use his algorithms to provide real time optimisation of the control parameters from very limited data. P&G are rolling this out as a tool in all of their drying plants.

3. References to the research

[R1] Chaigneau, E., Wright, A. J., Poland, S. P., Girkin, J. M., and Silver, R. A. (2011). Impact of wavefront distortion and scattering on 2-photon microscopy in mammalian brain tissue. *Optics Express* **19**, 22755-22774. DOI: 10.1364/OE.19.022755. Leading optics journal and now one of the most highly cited AO brain imaging papers.

[R2] Bourgenot, C., Saunter, C. D., Taylor, J. M., Girkin, J. M., and Love, G. D. (2012). 3D adaptive optics in a light sheet microscope. *Optics Express* **20**, 13252–13261. DOI: 10.1364/OE.20.013252. First and most highly cited paper on the use of adaptive optics in a light sheet microscope.

[R3] Mozharov, S., Nordon, A., Girkin, J. M., and Littlejohn, D. (2010). Non-invasive analysis in micro-reactors using Raman spectrometry with a specially designed probe. *Lab on a Chip* **10**, 2101–2107. DOI: 10.1039/c004248j. A novel optical approach to studying localised chemical reactions published in the leading journal on microfluidics.

[R4] Panter, J. R. and Kusumaatmaja, H. (2017). The impact of surface geometry, cavitation, and condensation on wetting transitions: posts and reentrant structures. *J. Phys.:Condens. Matt.* **29**, 084001. DOI: 10.1088/1361-648X/aa5380. Paper highlighted by JPhys+. The aim of JPhys+ is to highlight high quality papers published in any of the *Journal of Physics* journals.

[R5] Semprebon, C., Krüger, T., and Kusumaatmaja, H. (2016). Ternary free-energy lattice Boltzmann model with tunable surface tensions and contact angles. *Physical Review E* **93**, 033305. DOI:10.1103/PhysRevE.93.033305. This work has been cited over 40 times and it has been chosen for PRE Kaleidoscope.

[R6] Bower, R. G., Vernon, I., Goldstein, M., Benson, A. J., Lacey, C. G., Baugh, C. M., Cole, S., and Frenk, C. S. (2010). The parameter space of galaxy formation, MNRAS **407**, 2017-2045. DOI: 10.1111/j.1365-2966.2010.16991.x. This is the top astronomy journal and the paper has over 110 citations. It is one of the first publications using machine learning/Bayesian approach to understand important parameters in galaxy formation.

The underpinning research outputs have been published in the most relevant peer reviewed international journals and the total citations to date exceed 300.

4. Details of the impact

As outlined, the research expertise and knowledge of academics in Physics at Durham has been applied in a variety of different focused research interactions that have directly generated substantial wider impact through their effects on P&G products and processes.

For background, P&G is a leading global manufacturer of consumer goods with 5 billion customers worldwide. The relationship between Durham and P&G started with research projects in Physics and to date there is a portfolio of 100 projects in Durham Physics, Chemistry, Life Sciences, Computer Sciences and the Business School, leveraging GBP24.5million of funding. The impact of the collaboration is well evidenced by the fact that the relationship has been recognised as "best in class" numerous times (e.g. the RSC Teamwork in Innovation Award in 2015 [E3]), and mentioned as a best practice example in the UK Wilson business review [E5], the US Governor Association conference [E4], and an EPSRC case study [E6]. Based on this relationship, Professor Girkin ran an Open Innovation workshop with the IOP [E7] with 14 companies attending.

The research arising from the Durham-P&G relationship has delivered significant wider economic impact in the region [E8], as highlighted by the statement from a senior P&G staff member at Longbenton, that it *"helped to cement the role of the Longbenton Technology Centre within the P&G infrastructure", "safeguarding over 300 jobs in the Northeast"* [E1]. The relationship has also helped build relationships between P&G and the Centre for Process Innovation (CPI) catapult, that was instrumental in bringing the National Formulation Centre to the North East [E10]. The GBP14million project CEMENT between Durham, P&G, CPI and Peerless specifically created 50 highly skilled jobs in the North East. It was essential for the creation of the University's Centre for Innovation and Growth, awarded GBP10million from the North East LEP (Local Enterprise Partnership) [E9].

With respect to the specific research examples, the following sections detail the wider impact arising from the application of novel microscopy to improving grease removal, the application of computational methods to increase cleansing efficiency and optimising superhydrophobicity, and the application of artificial intelligence methods for optimising production processes.

3D Optical Microscopy Research into Grease Removal

In product development, Professor Girkin's research developing the "World's Smallest Washing Machine" has beneficially impacted P&G in two different and significant ways. First, the 3D optical microscopy [R1-3] has impacted on P&G business by allowing them to test new formulations of lipase-based laundry products (e.g. for Tide and Ariel) for grease removal using significantly lower levels of the functional compound. Annually P&G spends USD10million on the development of new washing formulations and it was estimated that the work in Durham saved USD2million in internal costs. Second, a major target in laundry is for reduced energy consumption, both in the production of products (see later), and in the washing cycle. The imaging approach provides a novel route by which P&G has improved cold water washing, uniquely enabled by the Durham research. The discovery of the CO_2 release enabled P&G to modify their flagship laundry products (e.g. Tide) to stimulate this release, helping to "*blow the fat*" from the surface. "*The direct financial benefit of this improvement is very hard to quantify... In 2018 the laundry market value was around [USD]15bn, and we achieved a [USD]1.1bn increase in sales, and some of this is attributable to the improved formulation*" [E1]. Furthermore, variations of this optical method have been applied at a macroscopic level at the P&G Longbenton facility, to measure the cleanliness of glasses for the development of dishwashing products (e.g. Cascade, Fairy). P&G estimate they "*spend [USD] 500K/yr on such work*" [E1] and the instruments and associated methodology developed in Durham were aimed at "*significantly reducing this cost overhead"* [E1].

Computational Studies of Cleaning on Structured Surfaces

Understanding how liquids and semi-solids can be efficiently removed from solid surfaces is critical across many P&G product categories, from shampoos and detergents to paper towels. The computational work [R4, R5] of Dr Kusumaatmaja had impact for P&G with their product R&D in two different aspects: firstly, to identify suitable design parameters for so-called superhydrophobic

and liquid infused surfaces, prized for their superior liquid repellency; and secondly, to remove soil efficiently under constrained resources (water and surfactants) under different conditions (e.g. soil viscosity, mechanical perturbations). Experimental trial-and-error would *"require years of laboratory work … and will cost P&G multiple full-time staff members"*. Instead, the simulation results have reduced "*experimental time and resources by more than a half"* [E2].

AI Techniques for Optimising Spray Drying

Spray drying is an important energy-intensive step in laundry powder production, manufactured at the rate of 30 tonnes/hour in the UK, with current energy costs for the drying process estimated to be over GBP5million per annum [E1]. With commercial and environmental needs to reduce the energy use, the AI techniques developed by Professor Bower to model astronomical events were adapted to optimise the operation of P&G's blow-drying towers with real-time feedback. Based on the work already undertaken by Professor Bower [R6] and P&G Longbenton engineers, *"initial estimates and the work already undertaken a saving of 5% will be made. Not only will this save money for P&G it will also be a benefit in using less energy and hence reduce our* [P&G's] *carbon footprint"*. [E1]

In summary, the collaboration between Durham Physics and P&G has had strong impacts at multiple levels, from improvements in P&G laundry products (with global market share of 45%) through to inward investment and job retention in the North East.

5. Sources to corroborate the impact

E1. Statement from a Senior Director at P&G Longbenton, on Durham's work on using 3D optical microscopy and AI technology to improve the production of P&G laundry products (dated 20 November 2020).
E2. Statement from senior staff member at P&G Cincinnati on Durham's modelling of cleaning structured surfaces (dated 2 January 2020).
E3. Article from Royal Society of Chemistry website on the RSC's Teamwork in Innovation Award 2015 Winner: Procter & Gamble and Durham University Partnership (retrieved 24 September 2020).
E4. Transcript (from minute 35 onwards) of the 2012 Governor Association conference: Creating and Entrepreneurial Culture; http://www.c-span.org/video/?304528-3/creating-entrepreneurial-culture (relevant section: minutes 37 to 45).
E5. A Review of Business-University Collaboration by Professor Sir Tim Wilson DL, known as the Wilson review, published by the UK Government, February 2012 (page 26), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32383/12-610-wilson-review-business-university-collaboration.pdf.
E6. EPSRC case study on P&G and EPSRC - Strategic Partnership (issued 20 May 2015).
E7. IOP Open Innovation Workshop (18 June 2015): Programme and IOP News article (30 June 2015).
E8. Statement from former senior staff member at P&G confirming that the Durham relationship with P&G secured the status of the Longbenton Technology Centre (dated 16 November 2020).
E9. Article from The Northern Echo 'New centre aims to make the North-East a global innovation hotspot' (7 January 2014), https://www.thenorthernecho.co.uk/business/10919356.new-centre-aims-make-north-east-global-innovation-hotspot/.
E10. Statement from senior staff member of National Formulation Centre (CPI) stating that a key reason for its presence in the North East is because Durham University built a link with the Centre for Process Innovation (dated 12 November 2020).