Institution: University of Edinburgh

Unit of Assessment: UoA9 - Physics

Title of case study: Soft Matter Research: Inspiring Public Engagement and a Community Programme in Edinburgh

Period when the underpinning research was undertaken: 2007–2019

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:
Wilson Poon	Professor	1990–present
Michael Cates	Professor	1995–2015
Paul Clegg	Professor	2003–present
Davide Marenduzzo	Professor	2006–present
Cait MacPhee	Professor	2006–present
Vincent Martinez	Research Associate	2009–present
Aidan Brown	Chancellor's Fellow	2012–present
Job Thijssen	Reader	2007–present

Period when the claimed impact occurred: August 2013–December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Attribution: Edinburgh soft-matter physicists generated the world-leading, highly cited research that forms the foundation of our public engagement activities. Academics, postdoctoral researchers and students supported the delivery.

Impact: Raised aspirations, sparked curiosity, gave access to scientific knowledge, and improved attitudes to science and scientists amongst Edinburgh school children. Constructed a new forum in which such interactions can thrive. Educated and inspired the wider public, school pupils, teachers and librarians.

Beneficiaries: School pupils in Edinburgh, their teachers, families and communities, and the wider public.

Significance: Good working relationships developed between scientists, pupils, their teachers and families. Enhanced motivation of pupils typically less exposed to science to pursue these subjects, supported by heightened enthusiasm and knowledge in their families, local communities and the wider public.

Reach: Extended interaction with approximately 200 school children, their parents, teachers and local community through school visits, science clubs and a community science festival. Direct training of approximately 30 school teachers. Interaction with approximately 15,600 members of the public through one-off events. Engagement with millions more worldwide through TV, online videos and news stories.

2. Underpinning research

The underpinning research flows from an EPSRC program grant 'Design Principles for New Soft Materials' (EP/J007414, PI Mike Cates) [***R1-R6***], whose aim was to establish principles for the creation of a new generation of soft materials [***R1***]. Three classes of material form the basis of our public engagement: dense suspensions, complex emulsions and living materials.

Dense Suspensions: Cates and Wilson Poon led research that lays bare the complex flow behaviour of dense suspensions, which are encountered throughout daily life, e.g., chocolate and cement. Their research into model lab systems [***R2***] clearly shows how frictional contacts control the flow of such suspensions. A follow-up study explains how the 140-year-old 'conching' process makes chocolate smooth [***R3***].

Complex Emulsions: 'Pickering emulsions' (emulsions stabilized by colloidal particles) are the basis for many industrial formulations in food, cosmetics and pesticides, e.g., a vinaigrette is an emulsion of oil and water stabilized by colloidal mustard grains. Our research includes the demonstration of the 'bijel' [***R4***], a novel material where colloidal particles are jammed together into a complex surface that supports intricately intertwined microscopic fluid

channels. The dense interpenetration of liquid channels and porous surfaces makes the bijel a strong contender for the next generation of battery materials.

Living Materials: This focuses on incorporating bacteria and bacterial products into novel materials. In nature, bacteria form complex colonies called 'biofilms', which enable them to withstand assaults such as antibiotics. Biofilms help to spread infectious diseases and contribute to the growth of antimicrobial resistance, which is becoming a global health crisis. However, they are also used extensively in industry. Cait MacPhee has discovered how the surfactant protein BslA enables certain biofilms to protect themselves by forming a dynamic, self-assembling waterproof 'raincoat' at the biofilm surface [***R5***]. She is exploiting this work to develop novel stabilisers for slower-melting ice cream. Poon's research uses the bacteria themselves to generate novel structures. He has engineered light-controlled bacteria [***R6***] that rapidly respond to light patterns to form bespoke, microscopic structures.

3. References to the research

[***R1***] Brooks, N. J., **Cates, M. E**., **Clegg, P. S**., Lips, A., **Poon, W. C. K.**, and Seddon, J. M., Soft interfacial materials: from fundamentals to formulation, *Philosophical Transactions of the Royal Society A* 374, 20150135 (2016) https://doi.org/10.1098/rsta.2015.0135 *[1 citation, WoK]*

[***R2***] Guy, B. M., Hermes, M., and **Poon. W.C.K.**, Towards a Unified Description of the Rheology of Hard-Particle Suspensions, *Physical Review Letters* 115, 088304 (2015) https://doi.org/10.1103/PhysRevLett.115.088304 *[108 citations, WoK]*

[***R3***] Blanco, E., Hodgson, D. J. M., Hermes, M., Besseling. R., Hunter, G. L., Chaikin, P. M., **Cates., M. E.**, Van Damm, I., and **Poon, W. C. K.**, Conching chocolate is a prototypical transition from frictionally jammed solid to flowable suspension with maximal solid content, *Proceedings of the National Academy of Sciences* 116, 10303 (2019) https://doi.org/10.1073/pnas.1901858116 *[14 citations, WoK]*

[***R4***] Reeves, M., **Brown, A. T.**, Schofield, A. B., **Cates, M. E.**, and **Thijssen, J. H. J.**, Particle-size effects in the formation of bicontinuous Pickering emulsions, *Physical Review E* 92, 032308 (2015) https://doi.org/10.1103/PhysRevE.92.032308 *[20 citations, WoK]*

[***R5***] Bromley, K. M., Morris, R. J., Hobley, L., Brandani, G., Gillespie, R. M. G., McCluskey, M., Zachariae, U., **Marenduzzo, D.**, Stanley-Wall, N. R., **MacPhee, C. E.**, Interfacial self-assembly of a bacterial hydrophobin, *Proceedings of the National Academy of Sciences* 112, 5409 (2015) https://doi.org/10.1073/pnas.1419016112 *[45 citations, WoK]*

[***R6***] Arlt, J., **Martinez, V. A.**, Dawson, A., Pilizota, T., & **Poon, W. C. K.**, Painting with Light-Powered Bacteria, *Nature Communications* 9, 768 (2018) https://doi.org/10.1038/s41467-018-03161-8 [34 citations, WoK]

4. Details of the impact

Through a range of hands-on activities, talks and events, we draw on our research findings to explain the fascinating phenomena observed when handling soft materials. A key focus is to **develop lasting and positive relationships** with **school children, teachers** and **families** across deprived communities in our local Edinburgh area. This is to **increase the aspiration and ambition** of the children; to make them **aware of opportunities** within STEM and higher education more generally; and to **inspire** curiosity about the world around them. We complement this targeted engagement with one-off events for the public based on our research [***R1-R6***], e.g., at science festivals, open days (Figure 1, middle) and school visits. Over the past six years we have delivered 97 activities reaching 15,582 people [***I1, I2***].

Connection with Underlying Research: Our public engagement activities are often centred on hands-on exhibits developed from the underlying research. Examples are:

A) Shear thickening of cornflour-water mixtures. This mixture flows like a liquid if stirred gently but will crack like a solid when agitated more violently. The wonder engendered by this bizarre behaviour (Figure 1, left) is a great way to introduce participants of all ages to soft materials. Our fundamental research resulted in a radical reinterpretation of the phenomenon in terms

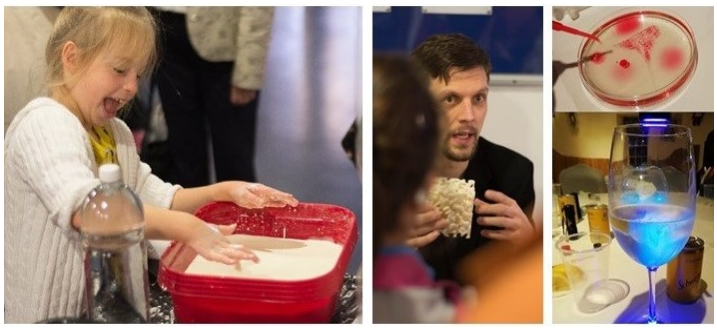

Figure 1: (*Left*) A joyful participant discovers shear-thickening fluids. (*Middle*) A 3D printed model aids Dr Thijssen's explanation of the bijel structure at an Open Day. (*Right*) The Marangoni effect and fluorescence at a #PhysicsofGin evening to engage school parents with physics.

of frictional contacts between particles [***R2***]. This allows us to explain this demonstration in much simpler terms than the prior theory, which involved hypothetical "hydroclusters".

B) A public engagement programme in the soft matter physics of food [***R3, R5***] including online videos produced with an Edinburgh film studio [***I3***], and live events on the physics of chocolate [***R3***], gin (Figure 1, right), beer, gluten-free bread, ice cream [***R5***], afternoon teas and caramel [***I1, I2***].

C) Live microscopy exhibits including pattern formation by light-sensitive bacteria and live speed measurements of swimming bacteria [***R6***]. These exhibits represent very closely the experiments undertaken in our research [***R4, R6***]. They also introduce school pupils to microscopy, which state schools rarely have access to. Videos [***R6***], pictures [***R4***] and 3D-printed sculptures [***R4***] are also drawn directly from our research.

These specific activities are complemented by more generic ones, e.g., making edible (and delicious) hydrogel capsules à la Heston Blumenthal. These activities are extremely hands-on and let the audience immerse themselves in the science. We have also run Physics Ceilidhs where our researchers choreographed soft matter themed dances based on, e.g., bacterial biofilms [***R5***]. Through these more general activities, our wide soft matter expertise, exemplified by the cited outputs [***R1-R6***], enables us to explain the underlying physics clearly. It would have been impossible to deliver without the years of soft matter research undertaken at Edinburgh, particularly through the EPSRC programme grant [***R1***].

Our programme was started and grown by Dr Anne Pawsey as the public engagement component of this programme grant. Due to the growing number of activities, we hired an Ogden Trust Outreach Officer in 2016, Dr JC Denis, who focused on targeted work with schools in our local community. Denis is also the Public Engagement and Outreach Officer for the National Biofilms Innovation Centre, which partly grew out of MacPhee's work on biofilms [***R5***]. Supported by postdocs and PhD students, Denis developed Harry Potter workshops (Figure 2) during which children make 'magical potions' based on complex fluids including cornflour-water (activity **A** above; [***R1***]), rheoscopic fluids (that glitter when they flow) and emulsions [***R4***]. These Harry Potter-based activities have proven very popular, with 2,353 members of the public taking part in events held in Edinburgh, including the Edinburgh International Magic festival, and 327 schoolchildren attending workshops in local schools and libraries (described in more detail below) [***I1***]***.***

Impact on Pupils in Deprived Communities Through a Community Partnership: Armed with a collection of soft matter activities and trained researchers and students providing delivery, the group then focussed on engaging with pupils in deprived communities with a view to Widening Participation. In 2017 Denis founded the Craigmillar Community Science Festival (CCSF) in partnership with four local schools, libraries, community projects and our Centre for Regenerative Medicine (CRM). He won the Edinburgh University Communities award for this work in 2019 [***I4***] (Figure 2). Craigmillar is in a very socially deprived area of Edinburgh (low ranking in the Scottish Index of Multiple Deprivation), and its schools have little history of graduation to STEM careers or higher education [***I5***]. Researchers and students from our research group supported school pupils to deliver activities for the festival [***I4, I5***], led a weekly science club for 18 p4-p5 pupils in Castleview Primary School [***I5***], and interacted with approximately 80 other pupils through school visits. Castlebrae Community High School describes the festival impact as "*huge*" and states it has "*transformed the perception of physics and science more generally both within the school and local community*" [***I6***]. Pupils at the

school "*are now consistently achieving National 4 science qualifications a year early (S3)"* which is *"better setting them up to achieve at National 5 in S4*" and parental engagement has also improved ("*Enthusiasm for both science and interactions with the school has increased ... more parents are answering phone calls, attending parent-teaching meetings, and simply being interested in school work*" [***I6***]).


Figure 2: (*Left*) Children discover emulsions at a Harry Potter-themed event. (*Right*) Dr Denis (right) is awarded the university's Community Partnership Award for his work in the Craigmillar community, alongside university and community colleagues.

The festival is now a 3-day-long, multi-site, annual event [***I7***] and an independent evaluation report of the 2019 event concludes that it "*effectively engaged a local audience in outdoor and indoor interactive STEM activities and fostered collaborations between participating individuals and organisations. … There is a strong desire for the annual community science festival to continue and there is growing recognition that it is beginning to make a significant and visible contribution to the cultural life of Craigmillar*" [***I7***].

The group's work with Castleview was part of the school's year-long entry for the 2019 Rolls-Royce School Science award [***I5***] and helped the school win this competitive national contest worth GBP15,000, which the school is reinvesting in their STEM work. Over this year the school surveyed 100 pupils and recorded a 15-20% increase in positive responses to 3 statements: "*I enjoy STEM*", "*I would like to get a job in STEM*", "*People like me get jobs in STEM*" [***I8***]. A survey of 40-50 of the pupils' parents yielded a 100% positive response to questions such as "*Is STEM education important?*" and "*Could your child have a STEM career?*" even though "*many [parents] also told us [the school] that before the project they did not know much about STEM and [did] not think it was interesting or relevant*" [***I8***]. The relationships built between pupils and scientists were key in these changes in attitude and aspiration. The teacher who led the Rolls-Royce entry states: "*In Craigmillar there has long been a significant poverty of ambition and low aspirations. Many pupils felt that 'people like me' don't do science or become scientists. Pupils entering University and professional careers are very much the exception. By working with and, perhaps most importantly, getting to know JC and his team, our pupils were able to build relationships with real scientists ... they began to see that anyone can become a scientist and that a scientist can mean a lot of things*" [***I5***].

Working relationships were also built with other local schools, including weekly science clubs at Castlebrae Community High School (2018-ongoing), St Francis RC Primary School and Craigour Park Primary School (both 2019-ongoing), and a holiday club organised by Edinburgh City Council (since January 2019). The club at Castlebrae has been correlated with an increase in the number of students choosing to study physics (from 2 to 6 students over 2018-2019; the club was the only thing that had changed from previous years) [***I6***].

The Harry Potter-based soft matter programme was provided to 6 schools in 2018 (in partnership with Edinburgh Libraries), reaching 327 children [***I1, I2***]. There is evidence of an immediate change in behaviour, e.g., after an event for 33 children at Sighthill Library, "*14 of the children obtained library cards for the first time that day, and 6 of these children are still regularly using them ... a strong result for this library*" [***I9***]. The programme also inspired Edinburgh Libraries staff, who went on to run weekly STEM activities over the summer of 2017 "*that they would not have done otherwise*" [***9***]. As the coordinator, Denis was invited to present this work at the Scottish Librarians' National Conference, which led to him developing STEM resources for the Scottish libraries 2019 Summer Reading Challenge; these have been used at over 22 libraries in Edinburgh [***I9***].

Impact on the General Public Through Events, Visits and the Media: Qualitative feedback was collected at several one-off events. 95% of 50 participants in a Girls into Physics event were "*more aware of opportunities in Physics and Engineering*" following its conclusion [***I2***].

After an emulsions workshop at an East Lothian primary school, most pupils had learned new basic facts, e.g., "*oil floats on water*", and "*oil and water don't mix*" [***I2***].

Our programme on the soft matter physics of food has reached at least 7,424 members of the public through online videos and in-person events, including groups who would not normally access science [***I1, I3***]. For example, 46% of 54 participants at a 2017 chocolate workshop [***R3***] at the Edinburgh Festival of Physics identified as 'non-scientists' [***I10a***]. Following the workshop, 68% and 92% agreed that their support for, and knowledge of, soft matter physics, respectively, had increased, and 96% enjoyed the event [***I10a***]. From July 2019 to December 2020, videos on the 'Yummy Physics' YouTube channel [***R3***, ***R4***, ***R5***] amassed 6,888 views [***I3***]. The comments on these videos ("*this was great fun, and I actually learned something new even though I've been watching cooking shows for decades!*"; "*Loved both the humor and the science"* [***I3***]) illustrate that viewers found them both enjoyable and educational.

Our soft matter and biophysics-based physics ceilidhs [***R5***] plus their associated science workshops in primary schools have reached 583 members of the public and schoolchildren. A 2018 science ceilidh workshop at Caol Primary School found that 80% of 50 children rated the workshops 4/5 or 5/5 and 70% agreed they would "*use science in the future*" [***I10b***]. Only 20% of the 55 participants at a 2018 ceilidh in Edinburgh identified as scientists, again demonstrating that our public engagement is effective at drawing in groups with lower science capital [***I10c***]. When asked what they enjoyed about their evening, answers included "*the new dances and research connections*" and "*learning about how to use dance to raise awareness and teach science"* [***I10c***].

Finally, Poon's chocolate research [***R3***] sparked global interest and was picked up by at least 97 news outlets, reaching over 5,000,000 people [***I11***]. This included: print coverage in the New York Times; online articles published in Turkey, Vietnam, Spain, India, and Italy; a feature piece on STV news in Scotland; and an interview with Poon on the Fun Kids Science Weekly podcast [***I11***]. MacPhee's work on BslA in ice cream [***R5***] was also reported on around the world: articles were published in the UK (BBC News, The Times, The Telegraph, and the Guardian) as well as Thailand, Australia, the United States, Pakistan, France, and Canada [***I12***]. The Guardian article generated 146 comments and 291 shares by members of the public, illustrating their engagement with the work [***I12***].

5. Sources to corroborate the impact

[***I1***] Higher Education Business & Community Interaction survey engagement returns listing live events and visitor numbers from August 2013 to July 2020. These are provided within a PDF document, along with URLs relating to specific events (where possible). Examples include event invites, videos filmed at events, post-event articles, and tweets.
[***I2***] Logbook records of events and visitor numbers (March 2017 to July 2020).
[***I3***] Yummy Physics: https://www.youtube.com/channel/UCTzDRqEBy03-BjKkBIYFt8w
[***I4***] Community partnership award: https://www.ph.ed.ac.uk/news/2019/community-partnership-work-leads-to-award-recognition-for-dr-jean-christophe-denis-19-04-10
[***I5***] Testimonial from the class teacher at Castleview Primary School who led the entry to the Rolls-Royce prize.
[***I6***] Testimonial from science teacher at Castlebrae High School.
[***I7***] Independent evaluation report of the 2019 Craigmillar Community Science Festival (page 21).
[***I8***] Castleview School's final report for the Rolls-Royce School Science Award (page 3).
[***I9***] Testimonial from the Lifelong Learning Development Leader at Edinburgh libraries.
[***I10***] Feedback forms and analysis from: **a)** chocolate making workshop (2017 Festival of Physics); **b)** 2018 Science Ceilidh workshop with primary school children; **c)** 2018 Science Ceilidh in Edinburgh
[***I11***] Some media coverage of [***R3***] is on Altmetric https://pnas.altmetric.com/details/54914726/news. Further coverage has been provided within a PDF document.
[***I12***] Some media coverage of [***R5***] is on Altmetric https://pnas.altmetric.com/details/3903948/news. Further coverage has been provided within a PDF document, including the Guardian article www.theguardian.com/lifeandstyle/2015/aug/31/longer-lasting-ice-cream-developed-scientists