Institution:
University of Cambridge

Unit of Assessment:
UoA9

Title of case study:
Mainstreaming Biological Physics in the Undergraduate Curriculum and Beyond

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

Material has been prepared for the Institute of Physics (IOP) to disseminate freely to universities worldwide who wish to incorporate material into the undergraduate physics curriculum. Donald was invited to lead this project – funded by the IOP – as Project Director, on the basis of her research at the University of Cambridge and leadership in the field. Beyond oversight of the teaching material and producing one lecture herself, she has been active in disseminating the challenges and excitement of the field to a wide range of audiences beyond academics through talks and online. This material is being accessed worldwide by many different universities. Within the UK, a number of universities are either using the course material directly or indirectly in their lecture course development, or are pointing students to the website as an additional resource.

2. Underpinning research (indicative maximum 500 words)

Professor (now Dame) Athene Donald has been a pioneer in biological physics research in the UK. She joined the University of Cambridge Department of Physics in 1983 where she has held a Professorship since 1998. Her research on biopolymers started during the 1980s, with very significant advances in the area of starch granule structure being made during the 1990s in a series of papers [e.g. 1-2]. She co-organised (with a pair of industrialists) two major international interdisciplinary meetings held in Cambridge in 1996 and 2000, involving both academics and industrialists with backgrounds across the research spectrum, from plant scientists to food manufacturers. Each conference resulted in the publication of a book that she co-edited. The work using microfocus X-ray scattering (SAXS) [1] to confirm the radial orientation of the amylopectin chains formed the basis of a News and Views article in Nature, highlighting the significance of the findings. The model revealed by SAXS was capable of identifying subtle differences with composition and between species and led to a successful collaboration with plant scientists at the John Innes Centre in Norwich e.g. [3] which enabled her to gain a broad appreciation of this interdisciplinary interface and be comfortable with the biochemical language and an appreciation of genetics and the issues surrounding genetic modification. Around this time, the late 1990s, she also served on BBSRC's Strategy Board and the Governing Body of the Institute of Food Physics, all work which familiarised herself with disciplines removed from physics, central to her ability to take oversight of a broad-ranging topic such as biological physics teaching. Her more recent work on protein aggregation ensures that she has a firm grasp of another of the key families of biological molecules [5].

Dr Pietro Cicuta become a Research Associate in the Department of Physics in 2003, became a Research Fellow in 2004 and was appointed to a Lectureship in 2006. His research focusses on soft matter and biological physics, with a particular emphasis on amphiphilic molecules such as lipids, including their interfacial properties [4-6]. By studying the thermodynamics of the molecules at interfaces it is possible to establish what the fluctuation spectrum of lipid bilayers should be in different circumstances and relate that to experimental data on both model and biologically-relevant bilayers. In particular by working with giant vesicles that mimic the composition of biological cell membranes, it becomes possible to understand the coupling between the phase behaviour and the membrane properties. This interplay between the thermodynamics and the response of the cell membrane is at the heart of the 6 lectures that Cicuta has contributed to the project.

Both Donald and Cicuta have broad experience in a wide range of biological physics arenas, covering the major classes of biologically-relevant molecules (with the exception of the nucleic acids). Due to their complementary interests they have also worked together and in 2007 wrote a joint invited review of microrheology as relevant to the study of soft matter and biophysics.

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

1 TA Waigh, MF Butler, I Hopkinson, F Heidelbach, C Riekel and AM Donald - 1997 -

Macromolecules 30, 3813-20. Analysis of the native structure of starch granules with X-ray microfocus diffraction, DOI: 10.1021/ma970075w.

2 PJ Jenkins and AM Donald - 1998. Carb Res 308 133-147. Gelatinisation of starch: a combined SAXS/WAXS/DSC and SANS study. DOI: 10.1016/S0008-6215(98)00079-2

3 AM Donald, TA Waigh, PJ Jenkins, MJ Gidley, M Debet and A Smith, in Starch: structure and function. eds AM Donald, PJ Frazier and P Richmond, RSC 1997, 172-179. Internal structure of starch granules revealed by scattering studies. (Available on request ISBN 0-85404-742-5).

4 AR Honerkamp-Smith, P Cicuta, MD Collins, SL Veatch, M Nijs, M Schick and SL Keller – 2008. Biophysical Journal 95, 236–246. Line tensions, correlation lengths, and critical exponents in lipid membranes near critical points DOI: 10.1529/biophysj.107.128421

5 P Cicuta, SL Keller and SL Veatch – 2007. J. Phys. Chem. B 111, 3328-3331. Diffusion of Liquid Domains in Lipid Bilayer Membranes DOI: 10.1021/jp0702088

6 Y-ZYoon, H Hong, A Brown, DC Kim, DJ Kang, VL Lew, and PCicuta – 2009. Biophysical Journal 97, 1606–1615. Flickering Analysis of Erythrocyte Mechanical Properties: Dependence on Oxygenation Level, Cell Shape, and Hydration Level DOI: 10.1016/j.bpj.2009.06.028

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

Within the UK Physics community Donald has a unique breadth of expertise in biological physics, which made her a natural choice to be the inaugural chair of the IOP's Biological Physics Group. This group was set up when the IOP felt, in the wake of the EPSRC International Review of Physics (2005) and the Wakeham Review (in 2008), that it was desirable that the growing UK community in this field was appropriately reflected within the Institute's groups. For the same reason – and also as a natural consequence of these two reports – when the IOP raised money from its resources (around £70k has so far been injected into the project) to initiate the preparation of teaching material to broaden the undergraduate curriculum in the UK, they invited Donald to take the lead in oversight of the project as Project Director. This is part of their desire to see biological physics fully recognized within the undergraduate provision of Physics Departments as part of teaching best practice.

The aim of the project is to produce material to facilitate the introduction of the topic of Biological Physics into the undergraduate curriculum, particularly for those departments which lack specific expertise in the field on their staff. Starting in 2009, when the IOP first approached Donald to put together a team of writers to create a body of work, Donald and Cicuta have been involved in the production of material. All the material now on the website has been checked and overseen by Donald. There is now a significant body of new material which has been uploaded onto the IOP's dedicated site. All of the material currently available is free to anyone who registers, from anywhere in the world (1). To date, the site has been visited more than 25,000 times, with more than 8000 unique visitors and an average of 1100 page visits per month.

The logic for producing this material was based on the comments in the Wakeham Review which stated:

- *'it is essential that students continue to be exposed to areas of the subject which are particularly applicable in the 21st century such as biophysics/medicine….*
- *physics students in many departments get regrettably little exposure, if any, to modern soft matter physics and biophysics.'*

The IOP took the lead in trying to change this situation by committing £70k to this project, having established – through a questionnaire sent to all heads of physics departments in the UK – that there was an unmet need that academics felt could be addressed by the preparation of suitable material. Responses to the question as to whether departments thought such material would be useful included (15 Physics Departments responded) 1) '*We would welcome suggestions for how biological physics could be used to enrich the physics syllabus. There are many biological examples that could be used to teach core physics while introducing the idea that physicists can contribute to the life sciences.'* 2) '*Any assistance in the development of material would be*

appreciated.' 3) '*Yes, we could well be interested - we would certainly be more interested in teaching such a course if the IOP could make course materials available to us, as we do not have substantial staff expertise in this area'*. These responses indicated a clear enthusiasm for the project to go ahead. Donald was involved in the project from the outset, assisted by a project management team who collectively made decisions on the topics to be covered and the authors to be invited to write each contribution.
Plans were sufficiently far advanced that in May 2011 a launch meeting was held, although at that time few lectures were actually available online (the IOP and IOPP - the Publishing arm of the IOP- have taken charge of all preparation of material to make web-ready). The launch was attended by around 40 people (including heads of departments) from different departments within the UK. Donald described both the project and the launch on her blog and has subsequently promoted the projects through articles in the Guardian and on the IOP's own website.

The online lectures– written by about half a dozen carefully chosen individuals from within the UK – have been viewed over 13,700 times. With her expertise in polysaccharides, Donald contributed the lecture on polysaccharides which has received 2399 individual page visits, as well as the introduction and overview; Cicuta wrote 6 lectures on thermodynamics and lipids which have in total received 4877 individual page visits. The lectures, comprising PowerPoint presentations, text, references and model questions with solutions, are designed to be used in a variety of ways as part of the philosophy of making the material as useful as possible to departments: some simply want examples that can be added in to existing lecture courses to make it easier to incorporate some basic material into their curriculum, others want to introduce whole modules. Which route each department takes depends on their course structure and the expertise they have on their teaching staff. The aim is to make sure that all UK departments introduce some material into their teaching, although currently the IOP have ruled out making any of the material a formal requirement of departmental accreditation, because that would take a long time to put into practice.

Within 6 months of launch there were an average number of over 1000 hits per month, with North America having the largest traffic, followed by Northern Europe (including the UK) and Southern Asia. Thus, although the project was designed with UK academia in mind, it is clearly reaching far beyond this initial target audience.

Already it is clear that more departments are introducing this topic into their courses, either simply prompted by the very clear message the IOP is giving out, or actually using the material being produced. For instance, in both Durham and Bristol new courses in biophysics/biological physics are being constructed which are accessing the concepts and material on the website. In Manchester, where there is a course in the 1st year but it precedes student exposure to thermodynamics, the course lecturer said *'During the last semester I directed the students in our first year course on biological physics to look at the IOP web site during the first lecture. Most of the lecture material is probably too hard for our first year (they do not cover the 2nd law of thermodynamics until second year), but they will profit from some of the videos and it is good to establish in their minds that biological physics is 'real physics' at an early stage.'*
The comment from Bristol was *'First of all, what an incredible resource! I feel like I've only just skimmed the surface of it, as every time I look at the notes, I find something else that is useful!....As this is my first time developing a lecture course from scratch, I was pretty overwhelmed. What the biological physics pages have done is given me confidence that a) I'm teaching the right things (as most of the syllabus I came up with on my own is covered by these lectures) and b) I have the foundations of a series of lectures that I can personalise with examples of my own… thank you (and to all involved) for doing these! It's taken a huge amount of stress away from me and has actually turned a job I was dreading into a slightly more manageable task!*
Other universities have reported using the site 'for inspiration' as to what to include, and as a source of figures to insert into their lectures. To date 5 universities have confirmed they are utilising the material in some form or other (Nottingham, Durham, Surrey, Manchester and Bristol) and Hull has indicated they will as soon as an appropriate course is rewritten.

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

1) Project website http://biologicalphysics.iop.org/ where all the teaching material can be found.

2) Compilation of responses to initial questionnaire sent out by the IOP

The project has been described in various blogs by Donald:

3) http://occamstypewriter.org/athenedonald/2011/05/18/a-work-in-progress/
4) and on the Guardian most recently http://www.guardian.co.uk/science/occams-corner/2013/apr/08/schrodinger-understanding-physcis-life .

5) A video describing the project can be found at http://physicsworld.com/cws/article/multimedia/2011/dec/08/physics-and-biology-a-match-made-in-heaven and this site also contains a video about the protein aggregation work and Cicuta's work on lipids.

6) Emails from the Associate Director, Education and Planning, IOP, regarding metrics

7) Statement from Manchester course lecturer

8) Statement from Bristol lecturer writing new course

9) Statement from Durham lecturer

10) Statement from Nottingham Lecturer