Institution: The University of Manchester		
Unit of Assessment: 5 (Biological Sciences)		
Title of case study: Re-animating school biology lessons through teaching with living flies		
Period when the underpinning research was undertaken: 2007 - 2020		
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:**
Andreas Prokop	Professor of Cellular & Developmental Neurobiology Senior Lecturer	2014 - present May 2004 - 2014
Sanjai Patel	Fly Facility Manager	March 2011 - present
Period when the claimed impact occurred: August 2013 - July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

University of Manchester researcher Prokop uses the fruit fly *Drosophila melanogaster* as a powerful model to study nervous system ageing and degeneration. Inspired by this work, Prokop and Patel launched the droso4schools initiative, collaborating with teachers to develop curriculum-relevant biology lessons using examples from their research and fly experiments that actively engage pupils. Their free lesson resources are downloaded worldwide, with >3,500 pupils on 6 continents having benefitted from this improved learning experience, as well as influencing pupils to choose science studies at university. Furthermore, droso4schools has inspired follower initiatives in Nigeria, Latin America, Indonesia, Croatia and Turkey, actively supported by Prokop and Patel.

2. Underpinning research

Axons are the cable-like processes of neurons that wire our nervous system. Most axons cannot be replaced and 40% are lost in old age, far more in neurodegenerative disorders e.g. Alzheimer's disease and Parkinson's disease. To find explanations for loss of axons, Prokop researched the mechanisms that actively maintain axons for an organism's lifetime. For this, he studies the microtubule cytoskeleton as an essential factor underpinning axon longevity. Since the roles and regulation of axonal microtubules are evolutionarily well conserved, Prokop chose to use neurons of the fruit fly *Drosophila melanogaster* as a model. This allows complex axonal biology to be researched more efficiently and cost-effectively than in larger animals, whilst still translating to biomedical applications.

Having studied >50 cytoskeletal regulators, Prokop proposed a conceptual framework explaining axon maintenance and pathology, based on a number of newly discovered and evolutionarily well conserved mechanisms: (i) Spectraplakins bind and regulate microtubules in ways that promote their bundle conformation typical of neurons; the mechanisms discovered can explain the human neurodegenerative disorder *hereditary sensory and autonomous neuropathy* [1, 2]. (ii) Efa6 is a so-called cortical collapse factor at the axonal surface that can eliminate aberrant microtubules; the loss of this mechanism can explain the human neurodevelopmental disorder *congenital fibrosis of extraocular muscles* [3]. (iii) Regular ring structures formed by the cortical actin cytoskeleton occur all along axons in mouse neurons; Prokop showed that they are evolutionarily conserved in flies and play important roles in maintaining microtubule bundles, which could explain neurodegenerative disorders linked to human components of cortical actin [4]. (iv) Spectraplakins act together with Tau to regulate the formation and maintenance of synapses and can be predicted as major players in neurodegenerative diseases classed as tauopathies [5]; this has recently also been proposed by others in the context of Alzheimer's disease suggesting potential conservation of underlying mechanisms.

Prokop's discoveries were made possible by using the fruit fly *Drosophila melanogaster* as a model with which to decipher complex mechanisms, much harder to achieve in vertebrate studies. During the course of his research it became clear that *Drosophila* could also be used to teach school students both the concepts and experimental skills of modern biology [6].

3. References to the research

1. Alves-Silva J, Sánchez-Soriano N, Beaven R, Klein M, Parkin J, Millard TH, Bellen HJ, Venken KJT, Ballestrem C, Kammerer RA, **Prokop A** (2012). Spectraplakins promote microtubule-mediated axonal growth by functioning as structural microtubule-associated proteins and EB1-dependent +TIPs (Tip Interacting Proteins). *J Neurosci* 32, 9143-58. (http://www.jneurosci.org/content/32/27/9143.full; *84 citations on Google Scholar, 3 November 2020)*
2. Sánchez-Soriano N, Travis M, Dajas-Bailador F, Goncalves-Pimentel C, Whitmarsh AJ, **Prokop A** (2009). Mouse ACF7 and *Drosophila* Short stop modulate filopodia formation and microtubule organisation during neuronal growth. *J Cell Sci* 122, 2534-42. (http://jcs.biologists.org/content/122/14/2534.long; *106 citations on Google Scholar, 3 November 2020)*
3. Qu Y, Hahn I, Lees M, Parkin J, Voelzmann A, Dorey K, Rathbone A, Friel CT, Allan VJ, Okenve Ramos P, Sánchez-Soriano N, **Prokop A** (2019). Efa6 protects axons and regulates their growth and branching by inhibiting microtubule polymerisation at the cortex. *eLife*. 8:e50319. (https://doi.org/10.7554/eLife.50319); *6 citations on Google Scholar, 3 November 2020*)
4. Qu Y, Hahn I, Webb SED, Pearce SP, **Prokop A** (2017). Periodic actin structures in neuronal axons are required to maintain microtubules. *Mol Biol Cell* 28, 296-308. (https://doi.org/10.1091/mbc.e16-10-0727; *55 citations on Google Scholar, 3 November 2020)*
5. Voelzmann A, Okenve-Ramos P, Qu Y, Chojnowska-Monga M, del Caño-Espinel M, **Prokop A***, Sánchez-Soriano N* (2016). Tau and spectraplakins promote synapse formation and maintenance through Jun kinase and neuronal trafficking. *eLife* 5, e14694. (https://elifesciences.org/content/5/e14694; * *AP is corresponding author; 27 citations on Google Scholar, 3 November 2020)*
6. **Patel S**, DeMaine S, Heafield J, Bianchi L, **Prokop A** (2017). The droso4schools project: long-term scientist-teacher collaborations to promote science communication and education in schools. *Semin Cell Dev Biol* 70, 73-84. (https://doi.org/10.1016/j.semcdb.2017.07.025; *9 citations on Google Scholar, 3 November 2020)*

4. Details of the impact

Context

Practical work is a key factor in engaging, enthusing and inspiring students, thus stimulating lifelong interest in science. High quality, appropriate practical work is central to effective learning in science ('The Importance of Practical Biology: from School to Higher Education', Royal Society of Biology, 2010). Therefore, Prokop and Patel worked with schools to incorporate their fly-based research and experiments into school biology lessons.

Pathway to impact

In 2012, Prokop and Patel began school outreach showcasing their *Drosophila* research. Feedback suggested increased value of embedding their research in curriculum-relevant practical biology lessons. In 2015, they founded the droso4schools initiative, supervising university students placed as teaching assistants in two local partner schools, and jointly developed 6 practical GCSE/A-level biology lessons using experiments from Prokop's research.

Drosophila-based school experiments are feasible and memorable: for example, using the climbing assay, pupils compare performances of young, aged and *tau* mutant flies [5], measuring, graphing and statistically analysing data as done in Prokop's work [1,2]; to understand genetic concepts and their applications in neurobiological research, pupils microscopically identify typical marker mutations [e.g. 3,4]; paralytic and epileptic flies illustrate the importance of axons, action potentials and synapses [5].

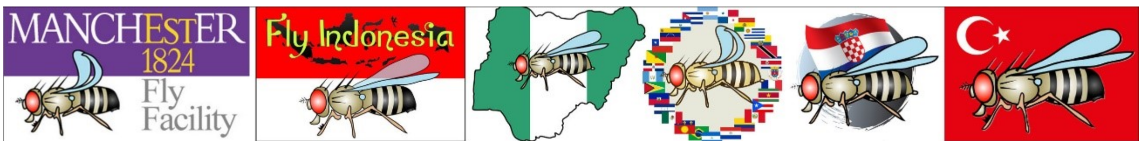
Title of the droso4schools website with online lessons, teacher info and links to all resources

Prokop and Patel promoted their lessons through:

i. school visits and UK-wide teacher training events organised with national STEM organisations e.g. the Science Learning Partnership (74 school visits and 16 Continuing Professional Development events);
ii. providing lessons and preparation, delivery, homework and revision resources freely online (droso4schools.wordpress.com);
iii. their two educational 'Small fly: BIG impact' YouTube videos;
iv. school journal articles about droso4schools and Prokop's research;
v. supporting droso4schools-type initiatives worldwide;
vi. engaging with AQA examination board to inspire examiners about *Drosophila*-related topics.

Reach and significance of the impact

droso4schools' reach is evidenced by lesson downloads (>2,570 [A]), website accesses (>109,000), YouTube video views (>38,000; and translated by others into Spanish, Indonesian, Arabic, soon Portuguese [B]), school article downloads (>6,125), follower initiatives worldwide (Fly Indonesia, droso4Nigeria, droso4LatAm, droso4schools-Croatia, droso4Turkey [C]), and lesson translations (5 Spanish, 5 Turkish, 2 Indonesian [A]).



Logos of international school initiatives using droso4school strategies and translated resources

ManFly's educational movie was translated by other teams into Spanish, Indonesian and Arabic

Changing the way biology is taught in schools

Provision of the necessary materials and support enabled teachers to deliver the lessons independently in their classrooms.

The then leader of Science Learning Partnerships in the North West) stated: "*It makes the teacher feel excited .. so they can pass that on to the student .. before .. the only thing I did with [flies] .. was genetic crosses. It's just so interesting to see the breadth and the use of Drosophila now*" [D].

26 teachers from 15 countries in six continents reported using droso4schools resources, benefitting >3,500 pupils worldwide [E], though the >2,570 lesson downloads suggests actual usage is higher. Prokop and Patel's evaluations showed:

- 90% (170 pupils/6 evaluations) gained new understanding of the nervous system and its study
- 91% (646/15) had increased knowledge/understanding of life sciences
- 51% (534/14) were more likely to study life sciences
- 78% (586/14) found the lessons useful for their curriculum

Feedback from teachers [F] showed:

Increased engagement/knowledge:

Harris Academy, London (36 pupils over 2 years):
"*Following success with one class, it .. has subsequently been embedded into our curriculum teaching for Year 12"*

Birkenhead School (1,200 pupils over 7 years):
"The flies .. can be used for simpler ideas at GCSE and then the same pupils meet the flies again to do more complicated things with them at A level. This generates the most ideal learning experience you could possibly have!"

The King's School, Chester (90 pupils over 2 years):
"… when we looked at our end-of-topic test results we found that for many students this section was their highest performing topic. … several students said they understood genetic linkage much better for having performed the crosses."

Junction City High School, US (500 pupils over 7 years):
"I will be redesigning my curriculum and will review many of your resources for inclusion." (later confirmed as implemented).

Ponte de Lima School, Portugal (150 pupils over 2 years):
"The results have been excellent because the practical work in Portugal in regular secondary education has been little used …We intend to continue the Drosophila project for the next few years…"

Influence on education choices:

Cardinal Newman College, Preston (370 pupils over 5 years):
"… initially they [students] *had only considered studying medicine as the gold standard for anyone that excels in science .., but following the teaching using resources such as these, they start to look at alternatives and appreciate that being a scientist is such an important career too."*

Harris Academy, St John's Wood, London (36 pupils over 2 years):
"… last year we started Year 12 with about a dozen students who wanted to apply for Medicine, in the end only two applied and the rest choose to apply to degrees in the sciences instead."

Influencing examiners:

Since 2019, droso4schools materials have been highlighted to several hundred teachers at AQA science hub meetings at >50 schools; "*It is important to AQA that … they* [senior science examiners] *are kept aware of research developments and outreach programmes such as the 'droso4schools' initiative. This type of activity helps the examiners produce stimulating and novel question papers each year. We look forward to continuing our relationship with the 'droso4schools' initiative in the future.*" (AQA Curriculum Support Manager – Science) [G].

5. Sources to corroborate the impact

A. droso4schools webpage providing an overview of lessons and their translations and figshare repository with droso4schools biology lessons (showing number of downloads).

B. droso4public webpage providing an overview of educational YouTube videos and their translations.

C. Websites of international follower initiatives, acknowledging Prokop and Patel's contribution: Fly Indonesia, droso4Nigeria, droso4LatAm, droso4schools-Croatia, droso4Turkey.

D. YouTube video "droso4schools: bringing *Drosophila* back into classrooms" (July 2015) – partner teachers and Regional Development Leader for the Science Learning Partnerships in the North West speaking about the benefits of droso4schools in their hands.

E. Impact document listing events, outputs, metrics and feedback from beneficiaries worldwide, indicating use of resources.

F. Letters from teachers (March 2015 – December 2020), confirming the use and benefits of the fly lessons provided.

G. Letter from AQA Curriculum Support Manager – Science (19 June 2020), confirming the value of droso4schools for their teachers and examiners.