Institution: University of Oxford

Unit of Assessment: 8 Chemistry

Title of case study: UOA08-08: Chemistry at the Garden: using living collections to generate public interest in chemistry research.

1. Summary of the impact

A portfolio of Oxford University research, relating to the chemistry of natural products extracted from plants, has formed the basis of a substantial and multifaceted programme of outreach activity targeted at schools and the general public from 2011-2013. Research students and staff have collaborated with the Oxford University Botanic Garden to deliver multiple events including a poster exhibition, an audio trail, interactive guided walks and a 'solar fuels' stand at the prestigious 2013 Royal Society Summer Science Exhibition, with the emphasis on face-to-face in-depth interaction where possible and a strong link to Oxford Chemistry research. The events have educated thousands of people and helped to inform their views on, and enthusiasm for, plant-related chemistry. They have also engaged the interest and support of industry.

2. Underpinning research

A substantial body of research conducted at Oxford University since January 1993 has explored a range of themes relating to plant-derived natural products including complex natural product synthesis, artificial photosynthesis, nitrogenases, crystallographic analysis and asymmetric catalysis, mineral components of soil, studies on plant signalling and defence, measuring isotopes for archaeology, synthetic materials and the biological importance of plant-derived compounds. Five examples at the heart of the public engagement work (described in sections 1 and 4) are highlighted below.

Edward Anderson (Lecturer) has worked on a family of natural antivirals derived from *Schisandra rubriflora*, a Chinese plant used in traditional medicine which grows in the Oxford Botanic Garden. This work not only includes total synthesis efforts towards these antiviral molecules, but also the development of new synthetic methodology that was only conceived because of the chemical / structural relevance to these plant-derived natural products [1].

Kylie Vincent (Lecturer) is developing new tools for understanding small molecule activation by metallo-enzymes including dinitrogen reduction by nitrogenase in soil and plant roots. The groups of Vincent and Armstrong (both Oxford) and Lance Seefeldt (Utah State University) used the control of electron transfer to nitrogenase via low-potential reductants or an electrode to study catalysis and ligand binding [2].

Fraser Armstrong (Professor) and Alison Parkin (Research Fellow at Oxford 2008-12) have applied the chemical principles of bio-catalysis to developing 'artificial photosynthesis' systems. The three fundamental components of such systems (light capture, electron source and fuel production systems) are studied as separate entities in the Armstrong Labs (e.g. enzyme-based bio-catalytic hydrogen production), with the ultimate aim of integrating these components into a scalable system with extended efficiencies and lifetimes. While at Oxford Dr Parkin pioneered the electrochemical characterisation of these bio-catalytic systems which are helping to develop an understanding of how to harness non-platinum metals in proof-of-concept energy devices [3, 4].

James McCullagh (Head of Mass Spectrometry) has explored plants in relation to archaeological chemistry. He has focussed on developing strategies for compound-specific palaeodietary reconstruction using mass spectrometry, and shown that carbon isotope ratios of amino acids from archaeological proteins can provide useful information about an individual's diet. In other studies his development of compound specific radiocarbon dating has made a significant contribution to understanding of the dispersal of anatomically modern humans into Europe [5].

Steve Davies' (Waynflete Professor of Chemistry) research since 1993 has included the development of asymmetric synthetic methods and total synthesis of natural products, including many derived from plants. X-ray crystallography is a key analytical tool for this research and is used for both characterisation of chemical structure and the determination of absolute stereochemistry of products [6]. The development and application of such crystallographic methods are a major focus of research within Chemical Crystallography in Oxford.

3. References to the research

Asterisked outputs denote best indicators of quality; University of Oxford authors are underlined.

[1]* A Palladium-mediated Cascade Cyclisation Approach to the CDE Cores of Rubriflordilactone A and Lancifodilactone G. Cordonnier M-CA, Kan SBJ, and Anderson EA, Chem. Commun. 23 (2008) 5818.*The natural product target for the Anderson laboratory research described in this publication is isolated from the Chinese herbal plant Schisandra rubriflora, which is grown at the University of Oxford Botanic Garden.*

[2]* Danyal K, Inglet BS, Vincent KA, Barney BM, Hoffman BM, Armstrong FA, Dean DR, Seefeldt LC. Uncoupling Nitrogenase: Catalytic Reduction of Hydrazine to Ammonia by a MoFe Protein in the Absence of Fe Protein-ATP. J. Am. Chem. Soc. 133 (2010) 13197. DOI: 10.1021/ja1067178 *This paper describes a technique for delivering low potential electrons to nitrogenase, which will enable new studies to understand the mechanism by which this important enzyme fixes atmospheric nitrogen into forms accessible to plants and its role in the global N cycle.*

[3]* Bachmeier A, Wang VCC, Woolerton TW, Bell S, Fontecilla-Camps JC, Can M, Ragsdale SW, Chaudhary YS, Armstrong FA. How light-harvesting semiconductors can alter the bias of reversible electrocatalysts in favor of H_2 production and CO_2 reduction. J. Am. Chem. Soc. Accepted September 2013. DOI: 10.1021/ja4042675 *This paper shows how the capability of a biological catalyst to produce solar fuels or feedstocks such as CO and hydrogen can be favoured by the semiconductor used as the source of electrons.*

[4] Wait AF, Parkin A, Morley GM, dos Santos L, Armstrong FA. Characteristics of Enzyme-Based Hydrogen Fuel Cells Using an Oxygen-Tolerant Hydrogenase as the Anodic Catalyst. J. Phys. Chem. C 114 (2010) 12003. DOI: 10.1021/jp102616m

[5] Marom A, McCullagh JSO, Higham TFG, Sinitsyn AA, Hedges REM. Single amino acid radiocarbon dating of Upper Palaeolithic modern humans. PNAS 18th April 2012. DOI: 10.1073/pnas.1116328109

[6] Davies S G, Lee J A, Roberts PM, Stonehouse JP, Thomson JEJ. Asymmetric syntheses of the homalium alkaloids (–)-(S,S)-homaline and (–)-(R,R)-hopromine. Org. Chem. 77 (2012) 7028. DOI: 10.1021/jo3012732

4. Details of the impact

The Oxford University Botanic Garden is the oldest botanic garden in the UK and a major tourist attraction in the city, with over 100,000 visitors from all over the world every year (ranked 16th of 92 tourist attractions in Oxford on TripAdvisor, July 2013). The research link between the UOA and the Botanic Garden goes back more than 100 years including the work of Sir Robert Robinson (who pioneered the isolation and study of bioactive compounds from plants in the early 20th Century); the Chemistry at the Garden public project has taken inspiration from this historical link and built on it to provide a public engagement project with contemporary relevance.

The series of collaborative outreach projects started in 2011, International Year of Chemistry, when an enthusiastic group of staff and research students from the Chemistry Department hosted a poster exhibition at the Garden. The posters told stories about the chemistry of plant-derived compounds, with titles such as “Poisonous plants: an unlikely source of medicine!”, “History molecules; plants and archaeology”, “When life gives you lemons...take some Miraculin”, “Natural Solar Fuels”. The exhibition was in a prominent location near the entrance to the Garden and there were over 14,000 visitors to the garden during the four-month exhibition (as recorded by ticket sales) [7]. The launch event for the exhibition was attended by the Lord Mayor of Oxford and other local councillors, as well as senior representatives from industry, business and the University. Comments from the Exhibition’s visitors’ book included: “*Fascinating information and communicated in a simple style for us non-chemists. Brilliant*!”; “*A very interesting exhibition and well presented. Found lots of information on plants found in my garden.”* [8]

From September 2012, highlights of this exhibition were developed into an ongoing Chemistry Discovery Audio Trail, which includes Anderson, Vincent, Parkin and McCullagh talking about aspects of their research described in Section 2. Acting on some of the feedback from the poster exhibition, each audio feature, delivered via an interactive map of the Garden, is accompanied by a chemical structure model of the compound being described. Over 400 visitors and 200 post-16 students and teachers have so far taken the trail [9] and there have been at least 1,700 downloads of the trail audio podcasts from iTunesU and the University of Oxford podcast page [9]. A video about the project is publicly available, featuring extracts from the chemistry audio trail and researchers talking about how highly they value the opportunity to engage with new audiences. The trail reaches an audience that might otherwise not engage with research of this kind, as evidenced by comments such as a 2012 review on TripAdvisor: *"The Chemistry trail – an audio system that accompanies you [on your visit] – ... gives some fascinating insights into the plants and why they are significant."* [10]. After a visit with his class a secondary school teacher commented *"Very interesting chemical stories told by real scientists. Excellent to see the molecular models next to the plants"* [11].


A molecular model on the audio trail

The next development was to introduce more face-to-face contact between academics and the general public. During May to July 2013, academics from the Chemistry Department (Davies, Anderson, Vincent, Sartbaeva and Cooper) delivered a series of guided walks around the Botanic Garden, using plants to explain key aspects of their research as in Section 2. Over 50 individuals attended the talks, and the intimate setting meant visitors were able to engage with the chemists in ways that had meaningful impact on their perception of science. Detailed written feedback was collected from all attendees, with one example stating *"I feel that what I have picked up "in small bits" has helped me read the science sections of public media in a more informed way."* [12]

One of the major themes from the Chemistry at the Garden project was selected for an interactive stand at the prestigious one-week Royal Society Summer Science Exhibition in July 2013. The topic, "Solving the Energy Crisis – from Ancient to Future Solar Fuels", linked directly to Armstrong and Parkin's research on artificial photosynthesis (see Section 2). During the week-long exhibition over 30 volunteers from the Department and the Botanic Garden, led by Rhiannon Evans (PDRA in the Armstrong group), worked on the stand. Always led by a member of the solar fuels research group, the exhibition received over 12,500 visitors, including 11,400 from the media, schools and the general public (official figures from the RS). The Oxford Chemistry team spoke directly with at least 3,000 visitors, measured by handing out stickers to everyone who engaged with the stand over the course of the week. The team also engaged online through social media, podcasts, the RSSE website (which received 83,000 unique visitors over the course of the exhibition), and the blog, where aspiring scientists posted results from a take-home chlorophyll experiment after visiting the exhibit, continuing after July 2013 [13]. The popularity of the stand was enhanced by a 'hands-on' approach with interactive demonstrations and experiments completed by hundreds of people. The activities linked to several aspects of primary and secondary school Science, Maths and Geography curricula and A-level Biology and Chemistry curricula. The strong impact of the exhibition on school pupils and their teachers was evidenced by requests for follow-up resource packs which were delivered to 84 UK schools, the majority of which had never been in contact with the Department of Chemistry before [13]. Since the exhibition the Department has been approached directly by students asking for further information about solar


A Chemistry Department volunteer engaging with school students at the RSSE

fuels science, including one Year 13 student at North London Collegiate School who wrote *"I was fascinated by your display at the Royal Society Summer Science Exhibition, and I believe others at my school would love to hear about your work too. We would be delighted if you would be able to talk to us about 'Ancient to Future Solar Fuels'."* [14].

The Department raised over £ 30,000 in sponsorship for the RSSE stand. One of the sponsors, the Royal Society of Chemistry (RSC), gave support for the Future Solar Fuels stand since the focus aligned with their own programme of activities, in particular the goal of raising public and political awareness of the environmental and economic potential of fuels produced using sunlight, as well as with the strength of UK research in this area. The RSC provided both funding and relevant materials for distribution, taking advantage of the stall as a 'channel to a wider audience', and welcoming the fact that the UOA planned to 'create a legacy from the stand' and promote future solar fuels beyond the RSSE. The RSC also valued the involvement of practising researchers on the stand, as well as the collaboration with the University of York researchers [15].

Finally, this sustained series of engagement beyond academia has established links with the outreach ambitions of industry. Since 2011, industry sponsors have included BP, Syngenta, Johnson Matthey, Infineum, AZ, Evotech, GSK, Basildon Chemicals and the Society of Chemical Industry (SCI), plus the donation of equipment by Locktronics/Matrix. Syngenta and SCI both sponsored the event because they saw its value in informing and enthusing the general public about the society benefits of plant chemistry [16, 17]. BP's Chief of Staff stated: *"The summer exhibition is a great way to engage current and future scientists and the general public and to raise awareness of science in general. Your exhibition on 'Solving the Energy Crisis – From Ancient to Future Solar Fuels' will be an interesting and informative example."* [18] The generous donations in support of the project have provided sustainability – the RSSE exhibit will be taken to the 2014 Big Bang Fair (estimated 60k visitors).

5. Sources to corroborate the impact

[7] Spreadsheet (on file) corroborating visitor numbers to the Botanic Garden during the poster exhibition.

[8] Poster exhibition visitors' book (held on file) corroborating the impact on visitors and increase in understanding of, and interest in, the chemistry presented.

[9] Corroboration of numbers of people taking the Chemistry Trail and audio downloads (on file).

[10] The TripAdvisor review appeared on 10 November 2012 and can be found at http://www.tripadvisor.co.uk/Attraction_Review-g186361-d531741-Reviews-or70-University_of_Oxford_Botanic_Garden-Oxford_Oxfordshire_England.html#REVIEWS .

[11] Teacher from Redborne Upper School and Community College, corroborating the positive impact of the Chemistry Trail (feedback form, held on file).

[12] Feedback corroborating the personal impact of the Summer Strolls event (held on file).

[13] Corroboration of numbers of visitors posting results on RSSE blog, and evidence of numbers of schools requesting packs, is held on file.

[14] Email from Year 13 student at North London Collegiate School (held on file), corroborating their continuing interest in the RSSE exhibition topic, and requesting a visit.

[15] The Senior Programme Manager at the RSC can be contacted to corroborate the reasons for the RSC's support of the RSSE stall.

[16] The Senior Research Chemist at Syngenta can be contacted to corroborate the reasons for Syngenta's support of the Chemistry at the Garden project.

[17] The Chairman of SCI Horticulture Group can be contacted to corroborate the reasons for SCI's support of the Chemistry at the Garden project.

[18] Quote from BP's Chief of Staff in sponsorship letter, and corroborating interest from UK Fuel industry (letter held on file).