

Institution: University College London		
Unit of Assessment: 9 - Physics		
Title of case study: Stimulating public interest and inspiring underrepresented groups through quantum biology		
Period when the underpinning research was undertaken: 2008-2020		
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:
Alexandra Olaya-Castro	Professor of Physics	2008 - present
Period when the claimed impact occurred: Aug 2013 – Dec 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of Impact <p>Professor Alexandra Olaya-Castro and her group in the Department of Physics and Astronomy at UCL conduct research into the emergent field of quantum biology, developing theory that brings together modern quantum science, physical chemistry and biophysics. This research has been used to engage with the public through television programmes, exhibitions, public talks and interviews for the press and blogs, thus sparking interest, increasing knowledge and understanding of quantum biology while concomitantly aiding the increase in the number of women pursuing careers in science. The programme has engaged over 2,000,000 people locally, nationally and internationally.</p>		
2. Underpinning research (indicative maximum 500 words) <p>Quantum biology is one of the most exciting and emergent scientific fields of the 21st century bridging two main scientific areas – quantum science and biology. It investigates the possibility that quantum phenomena happening in the molecular scale of biological systems may be intimately involved in biological functions that range from avian navigation through enzyme catalysis to the most important energy conversion process on our planet, photosynthesis.</p> <p>Through photosynthesis, plants and algae use sunlight, carbon dioxide and water to produce all molecular oxygen on Earth and about 118 billion tons of biomass per year. The first steps of photosynthesis take place deep in the cell membrane, at the nanometre scale, where we find the sophisticated photosynthetic machinery composed of light-harvesting antennae and molecular reaction centres. Each of these biomolecular complexes consist of several chromophores, such as chlorophyll, bound to a protein scaffold, and are capable of absorbing photons and carrying out a series of ultrafast excitation and charge transfer steps with a quantum yield of over 90%, meaning, the energy of almost every photon absorbed is effectively transferred to reaction centres to initiate stable chemical energy conversion.</p> <p>Whether non-trivial quantum processes accompany these energy transfer steps and what the biological function of such quantum behaviour may be, are open questions currently widely debated worldwide. Professor Olaya-Castro has been leading and developing theoretical research in this interdisciplinary scientific field since she joined UCL in October 2008. Her research has (i) provided theoretical evidence of non-classical features influencing the performance of prototype photosynthetic complexes (R1-R3), (ii) proposed guidelines to engineer systems based on the microscopic behaviour of natural photosynthetic units (R4, R5), and (iii) contributed to the further development of the theoretical and experimental methods of quantum science to investigate complex molecular systems (R6).</p> <p>The research developed between 1st October 2008 and 31st December 2020 has been done in collaboration with six PhD students and five postdoctoral researchers under the supervision of Olaya-Castro. All these early career researchers have made significant contributions to the key research findings. Avinash Kolli, postdoctoral researcher from 2008-</p>		

2011, contributed to identify the principle by which coincidence of energy scales for collective electronic states and nuclei motions means that some molecular vibrations play a key role in the preservation of quantum coherence during ultrafast energy transfer (**R2**). Elaborating on this, Edward O'Reilly, a PhD student from 2009-2013 and postdoctoral researcher from 2013-2014, was a co-author of the breakthrough showing that exciton-vibration interactions determine truly quantum behaviour (involving many particles yet does not admit an analogue classical or semi-classical explanation) of photosynthetic systems (**R3**). Richard Stones, PhD student from 2012-2016, showed that such vibrational motions can lead to regulated performance of nanoscale photo-cells using photosynthetic complexes as a main working component (**R4**)

One of the key features of these photosynthetic complexes is that they operate in a regime where quantum coherent processes and the thermal environment enter into a rich interplay maintaining the system at the quantum-classical interface. Developing further theoretical understanding of this quantum to classical transition is therefore essential. To this end, Professor Olaya-Castro and a PhD student under her supervision, Thao Le, have proposed the concept of strong "quantum Darwinism", which explains and formalises the role of an environment in preserving or not quantum behaviour of the system that interacts with it. This research finding (**R6**) constitutes a new framework to investigate quantum effects in biomolecular systems.

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

- R1. Fassioli F, **Olaya-Castro A.** (2010) Distribution of entanglement in light-harvesting complexes and their quantum efficiency. *New J. Phys.* 12, 085006. doi:10.1088/1367-2630/12/8/085006
- R2. Kolli A, O'Reilly EJ, Scholes GD, **Olaya-Castro A.** (2012) The fundamental role of quantized vibrations in coherent light harvesting by cryptophyte algae. *J. Chem. Phys.* 137, 174109. doi:10.1063/1.4764100
- R3. O'Reilly EJ, **Olaya-Castro A.** (2014) Non-classicality of the molecular vibrations assisting exciton energy transfer at room temperature. *Nature Comm.* 5, 3013. doi:10.1038/ncomms4012
- R4. Stones R, Hossein-Nejad H, van Grondelle R, **Olaya-Castro A.** (2017) On the performance of a photosystem II reaction centre-based photocell. *Chem. Sci.*, 8, 6871. doi:10.1039/C7SC02983G
- R5. Scholes GD, Fleming GR, **Olaya-Castro A.**, van Grondelle R. (2011) Lessons from nature about solar light harvesting. *Nature Chem.* 3, 763. doi:10.1038/nchem.1145
- R6. Le TP, **Olaya-Castro A** (2019) Strong Quantum Darwinism and Strong Independence are Equivalent to Spectrum Broadcast Structure *Phys. Rev. Lett.* 122, 010403. doi:10.1103/PhysRevLett.122.010403

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

UCL research into the emergent field of quantum biology has stimulated significant public interest in this topic and increased the level of knowledge about quantum physics in school pupils, students and wider global non-academic audiences. UCL researchers have featured in television programmes, participated in exhibitions and music festivals, delivered a significant number of public talks worldwide and given interviews for press and blog articles, which have together engaged more than 2,000,000 people worldwide with quantum physics.

Television

Olaya-Castro's research on quantum effects on photosynthesis was featured in *The Secrets of Quantum Physics* – the first ever TV programme to cover the topic of quantum biology. It aired on BBC Four for the first time on 16 December 2014, and 7 more times **with a total audience of about 800,000 viewers (S1)**. Due to popular demand, the episode is also available online via YouTube and Dailymotion, and **it has been watched approximately 1,864,425 times** overall, with **more than 16,400 comments** and an overall 93% positive rating as of December 2020 (**S1**).

Olaya-Castro's research was also highlighted in *Magic Numbers: Hannah Fry's Mysterious World of Maths*, which was aired twice on BBC Four in October 2018, **with a total audience of 369,000 people (S2)**. Moreover, the same episode has been watched on YouTube 381,087 times with over 3,700 comments and an overall 96.7% positive rating (S2). The director of the programme commented: "Prof Olaya-Castro's contribution to the programme played a crucial role, **creating a greater understanding among the general public of fundamental biological processes**, and demonstrating how science research (which can sometimes seem quite esoteric) has a relevance to all of our lives - in this case quite literally!" (S3).

These shows were the first to bring quantum effects in biology to large general TV audiences and stimulated extensive public discussion about quantum biology as evidenced by the many comments posted online.

Exhibitions and music festivals

Olaya-Castro's research, and her track record in public and media engagement resulted in a successful proposal to exhibit the stall *Quantum secrets of photosynthesis* (QSOP) at the Royal Society's annual Summer Science Exhibition (RSSE) in 2016. The participation reflects a strategic decision to target this event as a vehicle for optimum science communication, whilst at the same time building a lasting legacy on the initial development by reusing resources produced for the RSSE.

In July 2016, the RSSE saw a larger-than-average attendance (S4) from **14,371 visitors** (gender-balanced), made up of GCSE and A-level students (2,697 from 140 schools and colleges), teachers (328), VIP guests (1,425) and other members of the public and media representatives (10,085). The Executive Director of the RS, Dr Julie Maxton, has personally thanked Olaya-Castro for the exhibit, saying: "the exhibit offered **a unique insight into the collision between plant science and quantum physics**" (S4). Indeed, among the **student visitors** (79% of whom were from non-independent schools), 80% of them agreed that the exhibit (i) **increased their interest in science**; (ii) allowed them to **discuss research with practicing scientists**; and (iii) **developed their understanding of science** (S4).

Alongside the exhibit, significant web-based resources were developed, all of which have a life after the exhibition. These included the exhibit websites and social media profiles (S5), as well as a web-based interactive resource. The video of the QSOP exhibit had been watched **approximately 3,500 times by December 2020, with a 100% positive rating (S5)**.

To further expand the reach and impact on non-academic audiences, Olaya-Castro's group used the successful experience of the 2016 RSSE to create a similar mobile exhibit on the QSOP appropriate for audiences attending music festivals. The group conducted several engagement activities at Glastonbury (June 2017 and June 2019) and Green Man (August 2017) music festivals and the UCL Bloomsbury Festival (October 2017). These events were attended by **135,000, 175,000, 20,000 and 25,000 people**, respectively (S6). The attendees were families with young children, teenagers, and adults between 18-24 years old. These engagement efforts **result in improving teaching practice and encouraging scientific interests**, evidenced by comments from **a primary school teacher** who was going to "**implement elements learned at the exhibition in her class**", and from an adult audience that "had been turned off by science by negative experiences in their early education, however [...] the QSOP stand and staff definitely made them feel positive towards science in general". Many conversations were carried out with parents whose children were thinking of science as a career option, and after visiting the stall they **understood a lot more about what scientists actually did and how interesting it was**, and they said that they "**would relay this new-found knowledge to their children**" (S6).

Public talks

Olaya-Castro regularly delivers public talks worldwide to communicate her research. Her public speaking has impacted audiences in the UK, Colombia and USA.

UK: Her talk on the role of quantum effects on photosynthesis at the Royal Institution (Ri) in March 2015 and the subsequent Ri Science Podcast were listened to 5,732 times (S7). Among the attendees, 86% "**learned something new**", 83.3% "**wanted to find more about**

the subject”, and 58.1% **“felt more confident about discussing this subject with others”**. The high quality engagement **enticed the audience to learn and participate**; as evidenced by the participants’ comments: “Quantum Biology is now fully accepted as part of mainstream science.” “Some quantum biology is well established, it’s not all Blue Sky thinking”, thus confirming that, following Olaya-Castro’s public engagement activities, a **change of attitude** towards quantum biology took place, from being understood as a niche field to mainstream and applied science (S7).

Her talk at the UCL Annual Physics lecture in December 2017 engaged alumni and the recording on YouTube has been watched **2,944 times** with a 97% positive rating (S7). A talk in November 2019 at King’s Place as part of the series “Bach, the Universe & Everything” engaged about 300 people consisting of families with early teen children. One of the organisers said: “We’ve had such great feedback” (S7). A female member of the public communicated via email saying: “your talk was among the most engaging scientific communications I have seen” and requesting guidance to pursue postgraduate studies in this field (S7).

Colombia: Olaya-Castro was also invited to speak at the second **TEDxBogotaMujeres** event in **Bogotá (Colombia)** in October 2016, in which she discussed her work on the quantum effects on photosynthesis and her career path as a female scientist. The event was sold out and had a **live audience of 820 people, and 7,442 online views** (S8). The scientific and inspirational content influenced a teacher (translated from Spanish) to “share it with students” (S8). The demographic of the TEDx participants were business women between 25-50 years old, students, and NGO workers. The organiser of the TEDx event, said the talk was **“motivating and inspiring. [Alexandra] makes a clear call to the need of change, inviting the audience to choose “the option b”, (...) moving people to try to fight and achieve what they love, overcoming the obstacles of life”** (S8).

On this topic, director of the *Magic Numbers* event also commented that “Prof Olaya-Castro is an **inspiring role model; her enthusiasm, passion, knowledge and cutting-edge research are subtly promoting both the rewards of a career in science research, and the message that gender is no barrier to success**” (S3). Although they are not the only factors, Olaya-Castro’s inspirational efforts have contributed to **the 12% increase in female student enrolment in physics** in UK universities from 2013/14 to 2019/20 (S9).

Olaya-Castro has delivered talks on her research at a wide range of universities in Colombia covering different socio-economic groups. Engagement of this kind is only nascent in Colombia and therefore her activities have impacted both disadvantaged and more privileged groups. Her talk at the Universidad Nacional (Bogota) in 2019 engaged over 400 undergraduate students many from low socioeconomic backgrounds, studying a variety of subjects (S10). Her talk at the Universidad de Los Andes in April 2018 engaged about 70 science students. The recording of this talk in Spanish has been watched on YouTube **1,741 times**, with a 98 % positive rating (S10). [Text removed for publication].

USA: In partnership with UneteLatino, a charity based in Central Florida (USA), Olaya-Castro delivered a series of talks on her research to over 400 students at the Colonial High School and the Valencia College, who are of Latin American and other ethnic minority backgrounds. She also held an open Q&A session about her research with public members of the Latin community in that area in February 2020. The recording of this conversation in Spanish has been watched **2,700 times** with positive comments (translated from Spanish) **“very educational and interesting”** (S10). This was the first time such public engagement with science event took place in this community.

Media coverage and blogs

Olaya-Castro’s research was featured in an interview in the Colombian newspaper *El Espectador* in March 2019 as one of the first women scientists to be featured in this newspaper (which has been shared on Facebook 11,108 times with 100% positive rating). This media coverage **has generated much international exposure of the research to Spanish-speaking audiences worldwide**.

Her research was also presented in the Basque blog ‘Mujeres con ciencia’ in March 2018. The Basque blog aims to **encourage scientific vocations among the youngest** by introducing science pioneers and women from STEM. The website had received **more than**

650,000 visits, and its Twitter and Facebook accounts are currently followed by **53,700 and 46,500 people**, respectively (**S10**).

A live interview on BBC world news in December 2017 (**S10**) allowed the participants to listen to Olaya-Castro speak about quantum science and photosynthesis and ask questions. The BBC interview has been watched on Facebook **44,000 times** and subsequently shared 341 times with an overall positive rating of 99.5%. This interview has **sparked significant international public discussion**. Comments from both **North and South America** include (translated from Spanish in some cases): “It’s great to listen to all that information. You make it **easier to understand**. Great work!”, “**What I am learning is new!** I am very glad to know that there are warrior people like her... keep going!”, “Congratulations! **Very inspiring!**” (**S10**).

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

- S1. BBC Four webpage on “The Secrets of Quantum Physics” (<https://bbc.in/2GorHjI>) and on YouTube and Dailymotion: <https://bit.ly/2I55dpF>; <https://bit.ly/2GARbcR>; <https://bit.ly/2ByXxWV>; <https://bit.ly/2WU4r26>
- S2. “Magic Numbers: Hannah Fry’s Mysterious World of Maths – Weirder and Weirder” - Broadcasters’ Audience Research Board BBC4 viewing data between 22 and 28 October 2018: <https://bit.ly/2tiFjnX> – and [S4] episode on YouTube: <https://bit.ly/2DvIvkT>
- S3. Letter from the Director of the “Magic Numbers: Hannah Fry’s Mysterious World of Maths” and The Open University OpenLearn webpage featuring “Magic Numbers: Hannah Fry’s Mysterious World of Maths”: <https://bit.ly/2TjYZGU>
- S4. Letter from the Executive Director of the Royal Society and reviews of the Summer Science Exhibition & Soirée 2016: <https://bit.ly/3dDGk2x>
- S5. Quantum secrets of photosynthesis – Twitter (<https://bit.ly/2thz5Vy>) and Facebook (<https://bit.ly/2WSa7cN>) profiles; Web-based interactive activity – <https://bit.ly/2THkdLB>; YouTube video: <https://bit.ly/2GGRROb>
- S6. Festivals websites and press covers: <https://bit.ly/2E3ZufK>; <https://bit.ly/2RQ8N6E>; <https://bit.ly/2TwLoZS> (corroborate the reported attendance figures), and UCL Public Engagement Train & Engage: Project Learning & Impact Form for the QSOP stall at Green Man 2017, Glastonbury 2017 and Bloomsbury Festival 2017
- S7. Ri talk on SoundCloud: <https://bit.ly/2SzleZ4>, and feedback data and attendees comments from the Ri talk. UCL annual physics lecture (2017) on YouTube: <https://bit.ly/2I7BU5H>. Colligated feedback from event organiser and an audience.
- S8. Testimonial e-mail from the organiser of the TEDxBogotaMujeres talk, and TEDxBogotaMujeres talk and comments on YouTube and Facebook: <https://bit.ly/2Dv1ZX5>; <https://bit.ly/2SkiPBS>; <https://bit.ly/2MTkNDm>
- S9. HESA webpage on Students Data: <https://bit.ly/2MGHRoP>
- S10 Dra. Alexandra Olaya Castro | Coloquio De Física on YouTube: <https://tinyurl.com/y4lapayq>; Article about the talk given by Prof Alexandra Olaya-Castro at Universidad Nacional as part of “Catedra Hipatia” (pag 36-39): <https://bit.ly/3qwuWJe>; Q&A session with Latino population in Orlando Florida: <https://bit.ly/2ZzHjsg>; El Espectador online article about Prof Olaya-Castro: <https://bit.ly/2W3FcJW>; BBC News | Mundo live interview of Prof Olaya-Castro: <https://bit.ly/2N1H7em>; Webpage on Prof Olaya-Castro’s research on “Mujeres con ciencia”: <https://bit.ly/2UOJxZA> and website statistics. Colligated testimonies from engagement event attendees.