Institution: University College London		
Unit of Assessment: 9 - Physics		
Title of case study: ORBYTS (Original Research by Young Twinkle Scientists): improving student attainment and teacher motivation in physics		
Period when the underpinning research was undertaken: 2000 - 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:**
Jonathan Tennyson	Professor of Physics	1985 - present
Sergey Yurchenko	Professor of Physics	2008 - present
Giovanna Tinetti	Professor of Physics	2007 - present
Nick Achilleos	Professor of Physics	2007 - present
Graziella Branduardi-Raymont	Professor of Physics	1979 - present
William Dunn	Research Fellow	2013 - 2018; 2019 - present
Period when the claimed impact occurred: 1 August 2013 to 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of Impact (indicative maximum 100 words)

UK physics faces chronic diversity issues, extensive shortfalls in subject-specialist teachers and 20% lower uptake of physics at A-level than in the 1980s. ORBYTS (Original Research By Young Twinkle Scientists) partners researchers with schools to involve children in UCL-based scientific research related to the Twinkle Spacecraft (to launch in 2023). Over the past four years, ORBYTS has grown to 30 school-researcher partnerships (involving approximately 1,000 pupils) with 100% retention of schools on the programme. It has enabled more than 150 school students to author 10 scientific publications. 75% of ORBYTS pupils are from groups under-represented or historically excluded in physics. Through direct involvement in UCL research and by providing relatable science role models, ORBYTS has produced well-evidenced positive changes in pupils' science attainment, aspirations and perceptions of science. ORBYTS has directly led to more students applying for A-level and University science courses. It has also increased teacher motivation and specialist knowledge of physics.

2. Underpinning research (indicative maximum 500 words)

Through ORBYTS, UCL researchers have collaborated with school students to explore molecular spectroscopy and exoplanet characterisation in three areas directly related to the Twinkle Spacecraft: MARVEL (measured active rotation-vibration energy levels); exoplanet detection and characterisation; and solar system atmospheres and magnetospheres.

<u>The ORBYTS (Original Research By Young Twinkle Students) approach</u>

The ORBYTS programme was founded on research into molecular spectroscopy and exoplanet characterisation at UCL. The researchers partnered with schools to involve students in UCL-based scientific research related to the Twinkle Spacecraft (to launch in 2023). Twinkle will utilise infrared spectroscopy to provide deeper insights into the composition of exoplanet atmospheres, solar system objects, brown dwarfs and stellar disks. The ORBYTS programme produces high accuracy laboratory spectroscopy data which will be used to analyse results from the Twinkle and other exoplanet characterisation missions. Crucial to the ORBYTS model is the integration of students into the research process as researchers. In the ORBYTS model, the UCL researcher visits a school every 1-2 weeks for two terms, acting as a mentor and working on active research projects with the students. The school students also visit UCL throughout the year for workshops with researchers and to deliver talks on their own research at an "ORBYTS conference". ORBYTS researchers facilitate pupils' learning of the required science background, train them on tools and coding, conduct data analysis and research with the students and jointly present and publish results with them. Because the nature of this collaborative research methodology was so innovative, UCL researchers published their reflections on the process in *Physics Education*, and the article now stands as an exemplary in-depth examination of a project in which school students formally collaborate with scientists for the creation of publishable research (**R1**). The successful implementation led to the methodology expanding to other UCL/Mullard Space Science Laboratory (MSSL) research projects. School research facilitated by ORBYTS now includes star formation, planetary aurorae and magnetospheric physics, planetary imaging, high red-shift galaxies, supernovae, solar physics and galaxy morphology.

MARVEL

The ORBYTS programme has made extensive use of the MARVEL (measured active rotation-vibration energy levels) technique for identifying the energies of different molecular transitions. Development and application of MARVEL is led by Jonathan Tennyson, originator of the procedure, with contributions from Sergey Yurchenko. Since its inception in 2007, MARVEL has been regularly updated and improved. Now widely used at UCL and elsewhere, MARVEL provides very accurate spectroscopic line positions for each molecule considered; these lines can then be searched for by telescopes. These lines establish the presence of the molecule in a given environment, and careful study of many lines can lead to further information such as temperature and pressure of the environment. The provision of reliable laboratory data in the form of highly accurate line positions is vital to this process. The MARVEL procedure involves, for a given molecule: 1) collecting all high resolution laboratory spectra for that molecule including uncertainties; 2) assembling it in a common format with common quantum numbers, cleaning and validating the data; and then, 3) inverting the spectra to give a highly accurate, validated set of energies that can be used to generate much more extensive spectra than those that have already been observed (**R2**). ORBYTS school groups typically adopt a molecule and carry-out the MARVEL processes on that molecule to identify its spectral line locations, and ORBYTS MARVEL research has produced publications analysing the measured high-resolution rovibrational spectra (**R3**).

Exoplanet detection and atmosphere characterisation

UCL's Centre for Space Exochemistry Data group specialises in studying the atmospheres of exoplanets (or planets orbiting other stars). This includes spectroscopy of planets, atmospheric modelling, and novel retrieval techniques (for example, machine learning and artificial intelligence). The group has utilised spacecraft such as Spitzer and the Hubble Space Telescope to identify and constrain molecular presence in the atmospheres of a range of planets, including in one instance the discovery of water in the atmosphere of a Super Earth (planet K2-18 b) (**R4**). The group is also leading space missions such as Twinkle and the ESA's (the European Space Agency) medium-class spacecraft ARIEL (PI: Giovanna Tinetti), both of which are dedicated to classifying the environments of planets and their atmospheres. To choose suitable targets for these spacecraft, it is important to have good constraints on a planet's orbital and characteristic parameters (eg orbital period and radius). One method for constraining this is through examining transits when a planet passes across the face of its star (as viewed from Earth), producing a dip in the light detected from the star. UCL exoplanet researchers have developed a suite of publicly available tools to analyse exoplanet light curves. With the Las Cumbres Global Observatory, ORBYTS school groups have been conducting exoplanet observations from Earth, and applying these tools (eg the HOPS code) to constrain orbital and physical parameters of exoplanets (**R5**). These measurements will be essential for observations by Twinkle, ARIEL and other spacecraft.

Solar system atmospheres and magnetospheres

Twinkle will also image solar system objects. For a planet's atmosphere to be protected from the stream of particles ejected from the Sun (the solar wind/space weather), it requires a robust magnetic field, which generates a protective magnetosphere around the planet. Auroral displays are key signatures of a magnetosphere and the processes that govern it. They also enable studies of fundamental plasma physics, in conditions that cannot be generated in Earth laboratories.

Jupiter produces the most powerful aurorae in the solar system. UCL/MSSL research led by Nick Achilleos, Graziella Branduardi-Raymont and William Dunn has been critical to characterising Jupiter's atmosphere and magnetosphere and to understanding what processes govern the transfer of energy at the planet. Recently, Branduardi-Raymont and Dunn led Jupiter observing campaigns totalling ~2+ megaseconds of time by NASA and ESA flagship X-ray observatories Chandra and XMM-Newton, coordinated with NASA's Juno spacecraft. To enable school students and researchers alike to analyse X-ray aurorae, Dunn created analysis tools that ORBYTS students applied to this unique set of Jupiter observations (**R6**).

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

R1. Silva C., McKemmish L.K., Chubb K.L., Baker J., Barton E.J., Gorman M.N., Rivlin T., **Tennyson J.** (2018) Original Research By Young Twinkle Students (ORBYTS): When can students start performing original research? *Phys. Educ.* 53(1):015020. doi:10.1088/1361-6552/aa8f2a

R2. Furtenbacher ., Csaszar A.G., **Tennyson J.** (2007) MARVEL: measured active rotational-vibrational energy levels. *J. Molec. Spectrosc*. 245**,** 115-125. doi:10.1016/j.jms.2007.07.005

R3. McKemmish L.K., Masseron T., Sheppard S., Sandeman E., Schofield Z., Furtenbacher T., Császár A.G., **Tennyson J.**, Sousa-Silva C. (2017). MARVEL Analysis of the Measured High-resolution Rovibronic Spectra of $^{48}Ti^{16}O$ *The Astrophysical Journal Supplement Series,* 228:2. doi:10.3847/1538-4365/228/2/15

R4. Tsiaras A., Waldmann I.P., Tinetti G., **Tennyson J.**, Yurchenko S.N. (2019). Water vapour in the atmosphere of the habitable-zone eight-Earth-mass planet K2-18 b. *Nature Astronomy* 3:1086–1091. doi:10.1038/s41550-019-0878-9

R5. Edwards B., Changeat Q., Yip K.H., Tsiaras A., **Tennyson J.** (2020). Original Research By Young Twinkle Students (ORBYTS): Ephemeris Refinement of Transiting Exoplanets. *Monthly Notices of the Royal Astronomical Society.* doi:10.1093/mnras/staa1245

R6. Wibisono A.D.,Branduardi-Raymont G., **Dunn W.R.** (2020) Temporal and Spectral Studies by XMM-Newton of1Jupiter's X-ray Aurorae During a Compression Event. *JGR Space Physics.* https://doi.org/10.1029/2019JA027676

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

ORBYTS began with a single researcher-school partnership in 2016 and has now reached over 1000 students at 30 partner schools. It has enabled more than 150 school students to author 10 scientific publications. Nine out of ten schools with paper authors are state schools, and eight of the published schools have one or fewer physics teachers at the school, with two having no physics teachers at all. The majority of students undertaking ORBYTS research projects are from backgrounds that are under-represented in science, and over 50% of UK pupils undertaking ORBYTS research projects are either eligible for pupil premium/free school meals, or are refugees or in care. The gender ratio for the programme in 2018/19 was approximately 50:49:1 Male:Female:Non-Binary — far more equal than the 80:20 male to female gender ratio at physics A-level in the UK, which reduces further professional science.

By integrating school students into the research process, ORBYTS has had three main areas of non-academic impact: 1) increasing aspiration and science capital for under-represented groups in science; 2) improving transferrable skills and attainment; and 3) deepening teachers' specialist knowledge of astrophysics. The team has now helped to set up similar programmes across the UK and globally.

__Increasing aspiration for under-represented groups in science__

The UK faces chronic diversity issues in physics, in terms of gender (only 20% of students studying physics A-levels are female), ethnicity (94% of physics academics are white), and socio-economic background (0.6% of students on Free School Meals (FSM) achieved A* in a science GCSE vs 3.5% for non-FSM). From the 150 school students the programme has supported to author scientific publications, more than 40 ethnicities are represented. By directly targeting under-represented groups, ORBYTS has impacted the aspirations and science capital of students in those groups. Through their research projects and repeated meetings with relatable science role models, ORBYTS pupils gain an authentic and deep understanding of the scientific process and what it is like to 'be a scientist'.

The programme positively reframes scientific work and increases student confidence – a key factor in limiting girls' uptake of physics according to the Institute for Fiscal Studies. The Chemistry Teacher at St Gilgens School said, "More than half of the students in the project are female—of these more than half are not currently studying physics. At a level where some students had "checked out" of physics (…) our project proved inclusive and kept girls from a broad range of backgrounds and subject choices believing that physics had something they could contribute meaningfully to… The confidence building I've seen them go through in the last few months has been amazing" (**S1**). A teacher at Marymount Girls International School and Holy Cross Girls School, said the programme delivered "highly-engaging and challenging astrophysics extension activities" at the girls' school that the school "would not have the time, brainpower or focus to be able to deliver" on their own (**S1**). Students also attested to an increase in both scientific knowledge and confidence. A pupil from Higham's Park School said, "ORBYTS has improved my self-confidence drastically" and "has opened many doors for me in terms of leadership roles and placements" (**S3**). Another ORBYTS student at Tiffin Girls School pointed to how it exposed them to life as a scientist: "We were dealing with data that we hadn't been exposed to before, gaining an insight into what it would be like to be a scientist or astrophysicist" (**S4**).

The consequences of this engagement with relatable role models and the scientific process has been that ORBYTS research projects directly increased uptake in STEM courses amongst groups who are under-represented in science. A teacher at Marymount Girls International School and Holy Cross Girls School said that "EVERY student who took ORBYTS while on their final year of GCSE decided to take Physics at sixth form", creating a 100% increase on previous 6 years of A-level physics uptake, which he called "a tremendous show of the programme's success" (**S2**). Another student said, "When I began my course I thought I might go into a philosophy field at university but the experiences I've had over the last two years helped to change my mind and I now have a number of offers of places for Mechanical and Civil Engineering courses. The ORBYTS project opened my eyes to the possibilities of science and increased my passion for the subject" (**S1**). The Head of Physics at Preston Manor School noted that involvement with ORBYTS has even helped students with their university interviews: "In the past two years our students at Preston Manor have managed to have two publications which has helped them in their university application forms and they have been asked about it in their interviews" (**S5**).

Even those students who do not go on to study sciences still report that their involvement in an ORBYTS research project has given them a life-long appreciation of science. A year 13 ORBYTS student at St Gilgens (and author on Wibisono et al. 2020) said, "I never thought Physics could be something I could do. Just being part of it showed me more possibilities of science I'd never even thought of and sparked interest in other parts of science which I will never forget" (**S1**).

<u>ORBYTS impact on transferable skills and student attainment</u>

Teachers pointed to the plethora of hard and soft skills their students have developed as a result of engaging with ORBYTS: "All but two students in the project speak English as a second language - their levels of scientific literacy and their scientific vocabularies have grown immeasurably. […] The team have also picked up a lot of transferable skills around the basics of coding for data science" (**S1**). Another said: "it is the set of skills they are learning that really sets this apart – advanced algebra, python programming, applying neural network and artificial intelligence principles, intense teamwork and friendly competition" (**S1**). This is echoed by: "[m]ore important than this stretching of understanding and even the glimpse of life as a researcher are the skills the students develop such as teamwork, resilience, organisation and not being afraid of asking questions!" (**S3**).

Students were especially enthusiastic about the skills they gained through ORBYTS. An ORBYTS student said, "I learned about simple computing language (python) for analysis

and realised it can be used by anyone - I had no idea about coding but now I realise it's something I can actually do" (**S1**). Another said that "this project helped me learn how to analyse data and work in a team and present the data like when we went to the science fair. I've never done anything like that before and I didn't think I'd be able to understand it enough to do it but it was something I really enjoyed" (**S1**).
A teacher noted that these skills had translated into higher attainment for students at his school. For example, despite the socio-economic challenges of their area and a shortage of physics teachers (only one in the school), the 2017/2018 Higham's Park school ORBYTS cohort achieved progress from GCSE to A-level physics grades that was in the top 1% across the UK. The ORBYTS research project is cited as a major contributing factor (**S3**).

ORBYTS impact on teacher specialist knowledge and motivation
While the school students directly involved in the research have clearly gained both skills and scientific knowledge, involvement with ORBYTS has also improved teachers' motivation and specialist knowledge which is particularly valuable because many of the partner teachers are not physics subject specialists. A teacher involved with project said it had been "very refreshing" to be involved in ORBYTS: "After many years of teaching the GCSE and A-level syllabus, it was exciting to think about a new area of science. Meeting the PhD students and course coordinators reconnected me with the excitement of studying science at university level and reminded me what science education can be about. Given the very high rate of loss of science teachers from the profession, having such opportunities for re-energising teachers can be very important for recruitment and retention of teaching staff" (**S6**).
Another teacher notes that it had not only enhanced his motivation to teach, but even changed his teaching practice itself, as well the subject knowledge of other teachers in his school: "As for how useful I've found the project - in a tough year with significant professional challenges to overcome, this has been a real 'get me out of bed in the morning' kind of project. […] The project has fed back down through the school with ORBYTS members giving presentations to lower year groups and it's even changed my teaching to my 13 year old students - all my magnetism stuff is now fed through the lens of the importance of our magnetic field and what the aurora on Earth tell us about the conditions necessary for life here. Multiple other staff have become involved and have had valuable subject knowledge gains and through the school publications the wider school community - parents have also become enthused and are talking with their children about the project even if they're not directly involved. ORBYTS is definitely one of the coolest things I've been exposed to in my 15 year career" (**S1**).

Spread of ORBYTS programmes across the UK and globally
ORBYTS projects are now being piloted at Lancaster University and Northumbria University. UCL researcher William Dunn ran an ORBYTS project from Harvard (published in (**R6**)) and now runs a similar programme with a partner school in Austria. Clara Sousa-Silva (author of reference (**R1**)) is now running the Harvard version, directly informed by the ORBYTS model (**S7**). The ORBYTS team has also been involved in discussions with Universities in Australia, the Netherlands, Hungary, and Austria to start further pilots.

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

S1. Testimonial from Chemistry Teacher at St Gilgens and his students.
S2. Testimonial from Biology teacher teaching physics at Marymount International School.
S3. Testimonial from Physics teacher at Highams Park School.
S4. Testimonial from ORBYTS student at Tiffin Girls School, physical copy available upon reqeust.
S5. Testimonial from Head of Physics at Preston Manor School.
S6. Testimonial from Physics Teacher at St Richard Reynolds Catholic College.
S7. Article "High schoolers discover four exoplanets through Harvard & Smithsonian mentorship program," The Harvard Gazette. https://bit.ly/3dUqKzN Date accessed: 13th March, 2021.