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Original Research By Young Twinkle Students (ORBYTS): when can students start performing original research?

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Abstract

Involving students in state-of-the-art research from an early age eliminates the idea that science is only for the scientists and empowers young people to explore STEM (Science, Technology, Engineering and Maths) subjects. It is also a great opportunity to dispel harmful stereotypes about who is suitable for STEM careers, while leaving students feeling engaged in modern science and the scientific method.


As part of the Twinkle Space Mission's educational programme, EduTwinkle, students between the ages of 15 and 18 have been performing original research associated with the exploration of space since January 2016. The student groups have each been led by junior researchers—PhD and post-doctoral scientists—who themselves benefit substantially from the opportunity to supervise and manage a research project. This research aims to meet a standard for publication in peer-reviewed journals. At present the research of two ORBYTS teams have been published, one in the *Astrophysical Journal Supplement Series* and another in *JQSRT*; we expect more papers to follow.

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Here we outline the necessary steps for a productive scientific collaboration with school children, generalising from the successes and downfalls of the pilot ORBYTS projects.

 Supplementary material for this article is available [online](#)

1. Introduction

Most countries in the world are experiencing a shortage in their STEM (Science, Technology, Engineering and Mathematics) workforce, despite having economies that are heavily reliant on such professions and the scientific and technological output they provide (e.g. [1, 2]). Given the current lack of diversity in STEM fields (gender, economic background, disability, racial, etc) there is pressure to make STEM careers more inclusive and accessible to young people from all backgrounds [3–6]. There is a widespread struggle to persuade a large proportion of young people that STEM careers provide good professional opportunities. This is particularly a problem with students of low socio-economic backgrounds and girls; see, for example, the report on the relationship between socio-economic status and science by [7], the review on participation of girls in physics by [8], and the reports on diversity in STEM by [9, 10] and [11]. There are many factors that contribute to the poor diversity of STEM careers. Two of the key obstacles in STEM uptake are a scarcity of role models (see e.g. [12]) and the apparent narrow applicability of any one STEM field (e.g. [11]). Looking forward, it is vital to provide an inclusive and supportive environment where students from under-represented groups are provided with both the tools and aspiration to pursue STEM careers.

Space is an ideal gateway into other STEM fields as it is both intrinsically multi-disciplinary and highly inspirational [13]. The space industry has been successful in inspiring entire nations for decades, and capitalising on that inspiration by maintaining education and public engagement programmes targeted at a large variety of young audiences [14–20].

Beyond the space industry, many schemes have been set up to foster links between the research world and young people in education, providing STEM ambassadors and role models. Within the UK, some prominent programmes include The Brilliant Club [21], the Researchers in Schools programme [22], and the Institute for

Research in Schools (IRIS) [23], which in early 2017 incorporates 13 different scientific research projects into schools, with more expected to start in Autumn 2017.

For undergraduate students, the opportunities have often gone beyond education and outreach to actually involving students in the research. Undergraduate research experiences (UREs) are reasonably widespread [24, 25]. Seymour *et al.* [24] survey the literature on the benefits of UREs, reporting the largest categories of benefits are: ‘thinking and working like a scientist’ (e.g. critical thinking and problem solving, increased knowledge and scientific understanding), ‘personal/professional gains’ (e.g. increased confidence and ability to do research, ‘feeling like a scientist’), and skills (improved communication, organisation, teamwork etc).

Deep engagement with science practice through a free-form research project increases student understanding of the scientific method and more broadly the epistemological foundations of science [26]. This understanding has had significant influence on both compulsory and voluntary science education worldwide; for example, in Australia, all 15–16 year olds are required to perform an independent research project, in the US, science fairs are prevalent and encouraged, while in the UK, CREST Gold awards are presented by the British Science Association to students for substantial scientific research projects. For most of these student projects, there is little if any direct link to the academic scientific community. However, there is a small but growing movement internationally to involve secondary school students directly in original research. Examples of such programmes are:

- Creating new instruments, e.g. Langton Ultimate Cosmic ray Intensity Detector (LUCID) [27].
- Building instruments using specifications, e.g. HiSPARC international research network [28].
- Collecting data using instruments in school, e.g. the radioactivity in soil experiment (RISE), UK experiment using CERN@

School particle detectors [29] and Melbourne University's 'Telescopes in Schools' programme [30].

- Analysing data, e.g. radiation data from the TimePix instrument on the International Space Station [31] and real astronomy data for the detection of new variable stars [32].
- Presenting research, e.g. the cosmic ray detectors exhibition in the 2015 Royal Society Exhibition [33], which was a collaboration between University of Birmingham and Bordesley Green Girls school and sixth form.
- Rocket Science: UK wide practical experiment investigating how seeds might be affected by exposition to space [34].

A small number of these initiatives have led to publications in peer-reviewed literature, for example, LUCID instrument [35] and the London pilot of the variable star Discovery project [32]. There has also been at least one research project with primary school students studying bee movements with a scientist [36].

The pilot programme presented here is ORBYTS: Original Research By Young Twinkle Students, which is part of EduTwinkle, the education and outreach arm of the Twinkle space mission. Twinkle is a proposed UK-led satellite that will characterise the atmospheres of planets orbiting distant stars (www.twinkle-spacemission.co.uk, [37, 38]). The initial ORBYTS projects focussed on the energy levels of molecules relevant for the study of extra-solar planets, but future research projects will aim to have links to the exploration of space, be that engineering, astrochemistry, stellar physics, computer science, or the origin of life.

The overall goals of the ORBYTS programme are as follows:

- (i) To provide young students with the tools and aspiration to pursue STEM subjects and careers.
- (ii) To widen participation from under-represented communities in STEM degrees and careers.
- (iii) To improve scientific literacy and provide high-level STEM training for school students in the physical sciences, data sciences and technology.
- (iv) To provide STEM role models for school students, and dispel harmful stereotypes regarding who is suitable for scientific careers.

- (v) Provide a rare opportunity for junior researchers to supervise and mentor a team while managing a project.

A set of initial projects were created in alignment with these goals, and with consideration of the needs and schedules of school students, teachers and junior researchers.

Since its inception, more than 70 students have participated in ORBYTS across 10 programmes and nine schools. Here we summarise the main conclusions from the pilot programmes, specifically concerning the planning and delivery of such as programme.

It should be noted, however, that no formal feedback process was in place throughout these programmes. Some qualitative feedback has been gathered through focus groups with the students and observations from teachers and tutors. Ideally, a more in-depth study will be undertaken during future projects. Nevertheless, what follows is, to the best of our knowledge, the most in-depth examination of a project where school students formally collaborate with scientists for the creation of publishable research.

2. Project overview

A typical ORBYTS project consists of a small group of secondary school students lead by a mentor. The teams meet fortnightly at the school for approximately two-hour long sessions. The scientific research topic can vary between projects, though the initial pilot programmes (see appendix A1 (stacks.iop.org/PhysEd/53/015020/mmedia)) relate to molecular spectroscopy, due to the nature of the research group where the ORBYTS programme originated (ExoMol, a group at UCL working on a database of high temperature molecular spectra for use in characterising cool stellar and exoplanet atmospheres, [39, 40]). In the UK school cycle, projects should begin during the autumn term, so that sufficient research time is available to the students before their summer examinations.

ORBYTS projects usually require the following elements:

- (i) A mentor, usually a PhD student or post-doctoral researcher. A mentor's role is to supervise and oversee the project, explain the relevant scientific concepts and make the key

scientific decisions beyond the expertise of the school students. The project topic should therefore be tailored to the mentor's research interests.

- (ii) A research project that is sufficiently self-contained to produce results within a school year. As with most scientific enterprises this cannot be guaranteed, but it is beneficial for the whole group to obtain results within a short time period.
- (ii) A school liaison, usually a teacher, who can help recruit and select students, and who can help with logistics, such as arranging meeting spaces. Ideally this role will be played by a science teacher, who can then also help provide links between the research project and the students' curricula. The school liaison should also provide pastoral support to the students. This link is also important for ensuring the scheme complies with school child protection policies.
- (iv) A small group of students (ideally 4–6 but this can vary) so that the group is large enough for the students to feel supported by a team but not so large that it becomes overwhelming to organize. Efforts should be made to ensure the group is diverse and inclusive, which may mean active interventions during recruitment as well as an adaptable approach to as many aspects of the projects as possible.
- (v) A supportive school that accommodates the mentor, students and the research as much as possible.

Full case study reports from all initial programmes are given in the appendix to this paper. These case studies include a description (i.e. number of students, tutor background, frequency of student-researcher contact etc), research project outline with scientific context and motivation, project plan and reflection on the implementation in terms of the project plan. These case studies include:

- Two consecutive years of multiple teams within Highams Park School, a state school in North East London.
- Two summer projects, full-time for six weeks, hosted by University College London and Aberystwyth University.
- Program at a new state school, Westminster City School.
- Program hosted by Highgate, a independently-funded school, through the Highgate Chrysalis Partnership Teaching, in collaboration with four different local partnered state schools, Grey Coat Hospital, Marylebone Sixth Form, Regent High School and Camden School for Girls.
- Program remotely done between St Brendan's College, Bristol and Aberystwyth University.

For each ORBYTS programme, a project plan was prepared in advance, with input from senior departmental members with experience in planning research projects, along with the tutors and wider ORBYTS education team. The project plan included proposed scientific outcomes and an approximate timeline for the different stages of the project. This provided a structure for the sessions and was essential to ensure an appropriate variety of research tasks and a reasonable goal for the ORBYTS students to work towards. The ideal situation is for a significant amount of progress towards publication of a peer-reviewed research paper to have been achieved for each group upon completion of the project. As with most research projects, these plans must evolve as the project progresses, with adjustments made in subsequent years of the programme.

2.1. Project outcomes

In between the fortnightly meetings between the students and the mentor, intermediate goals should be set with the ultimate scientific outcomes of the project in mind. Although all projects have an ultimate goal of producing publishable original scientific research, each specific project will vary in its general expectations for the students (see the appendix for more details on specific projects carried out thus far). In general, all groups should work towards achieving the following common aims:

- (i) Students should acquire the essential scientific background to the research topic through a combination of student research and active mentoring. All mentoring should aim to actively involve the students, keeping tasks interactive. Following the student's interests beyond what is required for the specific project is also encouraged.
- (ii) Students should complete the project having learnt and made extensive use of IT essentials

- (i.e. Excel, Dropbox, Google Drive and appropriate email use).
- (iii) Students are expected to develop significant technical knowledge of the science within the project, which often includes graduate level concepts.
 - (iv) Students should develop literature review skills, including an introduction to scientific journals and technical language, guidance on how to search for articles (e.g. using google scholar), how to create appropriate references how and to follow citations.
 - (v) Students should learn to perform data collation and critical analysis of the data that is gathered. Data science in general is a useful transferable skill that many ORBYTS projects are expected to touch upon.
 - (vi) Students are expected to write up and record the outcomes of their work throughout the project, culminating in the preparation and delivery of a presentation at the end, aimed at an audience consisting of both academics and non-academics.

The three initial ORBYTS groups, formed between students at Highams Park School and young scientists from University College London, worked towards creating spectroscopic networks for acetylene, titanium oxide and methane. All three groups have produced high quality research, with two associated articles already published in the scientific literature [41, 42] and another in preparation.

3. Logistics

3.1. ORBYTS team

An ORBYTS project requires collaboration and coordination between a few different bodies, independently of the exact nature of the research project. Ideally, a small amount of funding is desirable, to allow payment of PhD tutors and catering of ORBYTS events, particularly the opening and closing ceremony.

On the research side, there are three distinct roles (though more than one can be performed by the same person): ORBYTS mentor, ORBYTS school liaison and ORBYTS coordinator.

Usually, the ORBYTS mentors are young scientists with research that can be easily adapted

or compartmentalised to be performed by secondary school students. The mentor acts as supervisor and mentor to a small group of students and directs the scientific research. They will need to be DBS checked and able to commute to the students' school multiple times a term. Ideally mentors will be dedicated to outreach and educational projects, and should be remunerated. Mentors will be responsible for setting targets and providing all scientific support to the students throughout the project. There is currently no formal teacher training given to mentors, but this will be considered in the future.

The role of the school liaison can vary significantly between different ORBYTS programmes depending on their availability and interests, but they are the point of contact at the school who manages recruitment, provides resources, organises school-based administration, oversees pastoral issues and can provide support for mentors. The school liaison also will be the point of contact if concerns over a student's academic performance arises given the time and energy commitment that an ORBYTS project can entail. Where possible, teachers should help mentors highlight links with the curriculum and assist mentors in explaining complicated graduate level concepts to students by providing analogies to classroom work, and helping to convert the language to be more appropriate to the student's current understanding.

The ORBYTS coordinator manages the university-school relationship, financial aspects of the programme and events, though this role can be assigned to any of the other senior members of the ORBYTS team.

The target composition of the ORBYTS student team must be determined by the tutor, teacher and coordinator in consultation. Often, the ORBYTS programme is most beneficial for students in their second to last year of secondary school (first year of A-level for UK students) as they have not submitted university or scholarship applications. This timing also allows the possibility of some students taking on a co-supervisory role in the subsequent year if they wish, an almost unprecedented level of experience for a pre-university student. It is a crucial aim of our programme to encourage STEM participation by under-represented groups, particularly girls and those from lower socio-economic backgrounds. Diversity should be achieved by actively

presenting the opportunity to students of all backgrounds and genders, but quotas can be established if necessary. Recruitment usually takes place via a visit by the ORBYTS lead, mentor or other Twinkle staff member to the school; in this way, the recruitment talk doubles as an outreach activity at the school.

All ORBYTS projects, and the more extensive EduTwinkle initiatives, prioritise schools in low socio-economic areas. More privileged schools are considered under the condition that they fund or host projects for local under-privileged schools.

3.2. Funding models

The sustainability of this programme is greatly enhanced by paying the ORBYTS mentors at standard university demonstrator rates, or higher if possible, for session time and some preparation/travel time. For a typical project including 12 fortnightly two hour sessions, for 2016-17 this worked out at around 500 per group. Catering for opening and closing ceremonies also need to be considered. No expensive equipment has been required in the projects run thus far, but if any was required this would need to be taken into account. PhD students are not paid for time spent preparing publications resulting from the work of their ORBYTS team; this is a critical part of their scientific training and the resulting paper contributes to their career progression.

In the second year of the scheme some of the funding was derived from a private school who funded not only their participation in the scheme but also participation by four nearby states schools. This model worked well and has the potential to make the project sustainable; our plan is therefore to use it as a means of expanding the scheme.

3.3. Project timeline

At the early stages of the project, the ORBYTS mentor, teacher and coordinator should work together to establish an overall plan and time-line for the project. Important topics for discussion include frequency of meetings between students with and without their mentor, appropriate communication channel(s) and how the students' other commitments fit into the project

time-line—specifically their examination timetable but also any other extra-curricular commitments the students might have. It is also key to discuss the pitch of the project and level of academic language to ensure students are not overwhelmed. Mentors, teacher and coordinator should work together to establish an approximate timeline of research milestones early on, but care should be taken to ensure flexibility, as the exact progress of a research project is not necessarily possible to predict. The three also work together to help manage workload for the students over the length of the project, and adapt tasks to best suit individual student's skills and interests.

In general, the following skeleton timetable for a nine month project has been found to be suitable:

Month 1 Recruitment and outreach talk at school. Sign-up deadline set and recruitment and selection of students begins. Project outlines and desired outcomes discussed.

Month 2 Selected students visit to University or other research centre where they are introduced to the field and the context of the project. There they will meet their mentors and be organized into their groups. Previously this has included a tour of the institution (e.g. visit to lecture theatres and both teaching and research laboratories).

Month 2–3 Introduction sessions begin, with the escalation of technical concepts kept slow. Students are encouraged to research the field and its uses, as well as begin to familiarize themselves with the tools they will need for the remainder of the project (e.g. excel, unix, scientific literature).

Month 4–7 Fortnightly sessions continue. Mentors should be working towards executing the preliminary schedule, aiming to maximise the research goals while ensuring students get a well-rounded experience of the full research cycle. Schedule will be adapted by taking into account the many obstacles that inevitably arise, specifically the demands and abilities of the individual students.

Month 8 Break for exams as necessary. Students will have differing examination timetables and demands on their time, but the ORBYTS research can usually continue, even if significantly slowed down.

Month 9 Finalising research as required. Preparation of student presentation for a closing ceremony at the host institution. Certificates, awards and authorships are awarded to students where applicable.

Subsequent months may be used by the students to continue to participate in the final paper. Usually this will be done in the Summer time by those students who will become co-authors. Ideally, the paper is submitted within six months of the final project; however, this goal has only been achieved in about half of the projects so far.

3.4. Communication

Communication between students, mentors and teachers has been observed as one of the most significant and persistent issues with the majority of ORBYTS projects thus far. Email was extremely poorly utilised by students, as they viewed it as *'kind of slow and inconvenient'* and struggled to feel comfortable with the type of language used in formal communication. In some pilot programmes, permission was obtained from the school to use the Slack messaging system, typically used in business environments and less personal than other messaging systems. The ease of use in some cases resulted in much more effective communication, however not all were comfortable with or able to download the app onto a smartphone, which limited its success as a communication channel. Future projects will aim to use a variety of communication formats, to best adapt to the accessibility and security requirements of each school and group.

3.5. Student commitment

The minimum time requirement for a typical ORBYTS project is the ability to attend each fortnightly session, with obvious exceptions for serious personal or academic needs. However, beyond this bi-monthly commitment, student participation is recommended but voluntary. This is particularly important for providing accessibility to those from low socio-economic backgrounds who may need to work after school and as a result do not have significant extra free time. It has been observed that those students who are motivated to continue with a project will dedicate any extra

time they have to it, so it is important that mentors and schools are as flexible as possible, in order to accommodate such students.

From the outset, the difficulty of the work performed must be highlighted, and students prepared appropriately. The most stark difference is the more unstructured nature of the work compared to classroom, as well as the level of work being performed.

Students participated in opening (essential) and closing (voluntary) ceremonies that took place at the host university. These scientific events were good for framing the project, creating a sense of team and purpose, improving morale, providing networking opportunities for the students, giving students the chance to ask questions of scientists about science and university and providing exposure to real working environments. These events do require some support from the school in organising appropriate times and permissions to travel to the host institution. Friends and families were invited to the closing ceremony.

4. Student feedback

Two focus groups were run in February 2017, each with five students from the pilot ORBYTS projects and subsequent similar projects (see appendix A1), the feedback from which has been subsequently transcribed and analysed.

4.1. The learning process

Students recognised that explaining their project increased their scientific understanding, with one recalling the importance of explaining their project to family members to help retain information. This was formalised in the closing ceremony where students were given the chance to present their work in groups to a mixed academic and non-academic audience; alumni students talking to new ORBYTS students said this experience will *'help you understand it a bit more, when you are actually talking about it and explaining it to other people'*. Students also gained confidence in speaking to larger audiences and generally, as one pupil notes *'ORBYTS has improved my self-confidence drastically'* and that it has *'opened many doors for me in terms of leadership roles and placements'*.

Some of the specific technical skills students learnt will be useful in the future, most notably Microsoft Excel, with students stating that *'I did not really know how to use Excel and now I can use it a lot better'*. More broadly, students reported that the project had *'vastly improved'* their experiences with computers, with the discovery and implementation of skills such as how to debug a program, format input correctly, interpret error messages and learn new software. Students recognised the value of such skills, agreeing strongly when asked whether they could see the skills they developed as being useful in their future, including for non-science based tasks. In the words of one student, the programme *'has equipped me with a unique skill set which will help me throughout further education and later into working life.'*

Students spoke about the ORBYTS project allowing them to put their learning into context and that the experience has *'helped throughout my chemistry, physics and maths A-level'*.

As well as gaining confidence in *'independent work'*, students also gained significant transferable, career skills in communication, teamwork and independent motivation. One student identified that *'one of the challenges I overcame at the start was trying to have a good line of communication with everyone else'*, and emphasised that the main skills they gained were *'in the communication and team work'* areas.

A key observation of the ORBYTS mentors and teachers was the importance of allowing students to feel like they could ask frequent questions, and the confidence they gained if they were guided into finding the answer as opposed to being told. One of the many benefits of the programme for the ORBYTS mentors themselves is the opportunity to supervise and manage a research team, and to learn and practise skills that will be useful for their own careers. A full analysis of the impact on this sort of project on mentors and researchers will be discussed in future work.

4.2. Student experience

Most students expressed significant enjoyment of the experience, one stating that *'ORBYTS has been one of the best experiences of my life'*, which they attributed to a number of factors. Students found the sessions *'quite laid back'*. The lack of formal examination took the pressure out of the

experience and meant students felt they could *'learn new things'*, *'just out of interest...with no exam at the end'*. Students enjoyed learning university-level physics and chemistry with content that *'went beyond what we'd learnt in lessons'*. Overcoming the challenges of the difficult programme was clearly a source of pride, e.g. *'because although it was hard to understand, it felt like an achievement once you understood what was going on'*. However, it is worth noting that they found the project at times *'very confusing'*.

Common difficulties encountered by the students were insufficient motivation and insufficient direction, which can perhaps partly be attributed to a group too large for one mentor. This was tackled in the second set of projects by inviting students back to be part of a more supervisory role in overseeing the next cohort. The possibility of including undergraduate students in a co-supervisor role is also being considered for the future. It was found that the longer timescale of the project was found to be challenging by some students, especially in comparison to the more segmented class activities.

Students commented on the highly computerised nature of the research, with some commenting that they *'thought there might be an experiment'*. While future ORBYTS projects may incorporate a more experimental angle, particularly involving astronomical observations, this did not apply to any of the projects run thus far.

From the focus group feedback, it is clear that the uniqueness of the programme and the fact that they were *'working on something that actually will be considered real science'*, were key motivators for students.

4.3. Perception of science and researchers

Though some students mentioned having *'no idea what people did'* in research, most started with definite perceptions of research and researchers. Students were unanimous and strong in their agreement that the ORBYTS experience changed their perception of research. For example, students discussed the belief that research was a solo, not group, effort and described previous preconceptions of research as *'some independent thing where you learnt a lot of things and then you go away and you just have like a revelation and you*

spend hours on it, and that's it ... I did not think it was the group effort', that research involved 'just one person sitting doing all the number crunching finding everything out for themselves' or that 'people used to just go and do their own little experiments that they thought up and then found out this information'.

Students were not expecting the heavily computational nature of the research: *'one thing that shocked me about doing original research was just how much time was spent on computers. I'm not going to lie, when I signed up I thought there would be a lot more sitting and discussing ideas.'*

Students grew to appreciate scientists not as *'quiet people who are sitting alone doing their research, not interacting with anyone'*, but as *'really really normal nice people who just have a really really good understanding of one specific subject'*. Students identified their tutors as *'very friendly and nice'*, *'a lot less intimidating than I thought they'd be'*, *'laid-back'*, *'talkative'*, having a strong *'passion for the subject'* and who had worked hard to get to their position. Students appreciated the opportunity to talk directly with a scientist *'who really understands like every aspect of the project really really well and what they're researching'*. Students felt that *'even though it might be a relatively simple answer, they're always happy to help and answer'* and that asking questions was received positively by their mentors. These comments are encouraging in regards to the attempt to address key issues in STEM subjects such as the lack of relatable role models (e.g. [43, 44]).

5. Discussion

Collaborations between fields will be made in future projects to enhance links between different STEM areas and it is hoped that the inclusion of a strong educational component of the Twinkle Space Mission will enhance the ability of the programme to produce more highly trained STEM professionals to the future workforce and economy.

Space is a topic that does not need to work hard to create fascination. This makes it an excellent gateway for other, more seemingly impenetrable STEM fields, like robotics and engineering. The Twinkle Space Mission brings together aspects from chemistry, biology, physics, engineering, robotics and programming, and as such provides

a very suitable vehicle for engaging students with all STEM fields. The aim for ORBYTS in the near future is to expand into more schools, work with more research institutions, collaborate with scientists in different research areas, all in order to involve and inspire a wide range of school students in real science. EduTwinkle represents a concentrated effort to ensure that the inspiration and knowledge that a space mission provides can be embraced across society. ORBYTS in particular aims to extend the research effort beyond academics, making as many young people as possible involved and invested in the science of space. The huge volume of research needed to study every molecule, every star, every planet, is a much greater task than the current cohort of scientists can handle. But there are thousands of students who could be contributing to these discoveries. The ORBYTS programme brings state of the art science and technology into schools, where students perform original research and work towards publishing their findings, collaborating with scientists all over the country.

The answer to the question 'When can students start performing research?' is simply 'When you provide the environment for them to do so'.

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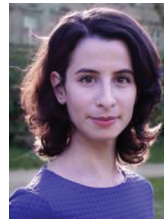
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<https://doi.org/10.1088/1361-6552/aa8f2a>

References

- [1] UK Commission for Employment and Skills 2015 High level STEM skills requirements in the UK labour market *UK Commission for Employment and Skills*
- [2] National Research Council 2011 *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics* (Washington, DC: The National Academies Press)
- [3] Penner A M 2015 Gender inequality in science *Science* **347** 234–5
- [4] Clancy K B H, Lee K M N, Rodgers E M and Richey C 2017 Double jeopardy in astronomy and planetary science: Women of color face greater risks of gendered and racial harassment *J. Geophys. Res.: Planets* **122** 1610–23
- [5] Archer L, Moote J, Francis B, DeWitt J and Yeomans L 2017 The exceptional physics girl *Am. Educ. Res. J.* **54** 88–126
- [6] Francis B, Archer L, Moote J, DeWitt J, MacLeod E and Yeomans L 2017 The construction of physics as a quintessentially masculine subject: Young people's perceptions of gender issues in access to physics *Sex Roles* **76** 156–74
- [7] The Royal Society 2008 Exploring the relationship between socioeconomic status and participation and attainment in science education *SES Sci. Educ. Rep.*
- [8] Murphy P and Whitelegg E 2006 Girls in the physics classroom: a review of the research on the participation of girls in physics *Technical Report* The Open University
- [9] Campaign for Science and Engineering 2014 Improving diversity in STEM *Technical Report* King's College London
- [10] Amna Silim and Cait Crosse 2011 Women in engineering: fixing the talent pipeline *Technical Report* Institute for Public Policy Research
- [11] Institute of Physics 2011 It is different for girls: influence of schools *Technical Report*
- [12] Bonetta L 2010 Reaching gender equity in science: the importance of role models and mentors *Science* **327** 889–95
- [13] Borne K D, Jacoby S, Carney K, Connolly A, Eastman T, Raddick M J, Tyson J A and Wallin J 2009 The revolution in astronomy education: data science for the masses (arXiv:0909.3895)
- [14] Rosendhal J, Sakimoto P, Pertzborn R and Cooper L 2004 The NASA office of space science education and public outreach program *Adv. Space Res.* **34** 2127–35
- [15] Mcfadden L A *et al* 2005 Education and public outreach for Nasa's deep impact mission *Deep Impact Mission: Looking Beneath the Surface of a Cometary Nucleus* (Berlin: Springer) pp 373–96
- [16] Peticolas L M *et al* 2009 The time history of events and macroscale interactions during substorms (THEMIS) education and outreach (E/PO) program *The THEMIS Mission* (Berlin: Springer) pp 557–83
- [17] Reis N T O, André C, Cline T D, Eastman T E, Maher M J, Mayo L A and Lewis E M 2009 NASA education and educational technologies exemplified by the space weather action center program *Education and Technology for a Better World* (Berlin: Springer) pp 14–25
- [18] Pounds K 2016 How the RAS helped launch Tim into space *Astron. Geophys.* **57** 1–11
- [19] Mason H E and MacRae H 2016 Space to earth challenge takes off in UK schools *Astron. Geophys.* **57** 2–9
- [20] Spacelink: the Helen Sharman Programme 2017 <http://spacelink.org/meet-an-astronaut/>
- [21] The Brilliant Club 2016 www.thebrilliantclub.org/
- [22] Researchers in Schools 2016 www.researchersinschools.org/
- [23] Institute for Research in Schools 2016 www.researchinschools.org/
- [24] Seymour E, Hunter A-B, Laursen S L and DeAntoni T 2004 Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study *Sci. Educ.* **88** 493–534
- [25] Russell S H, Hancock M P and McCullough J 2007 Benefits of undergraduate research experiences *Science* **316** 548–9
- [26] Jaber L Z and Hammer D 2016 Learning to feel like a scientist *Sci. Educ.* **100** 189–220
- [27] Whyntie T and Harrison M A 2015 Full simulation of the LUCID experiment in the

- low earth orbit radiation environment
J. Instrum. **10** C03043
- [28] Frossati G, Herbschleb C T, Oonk J B R and De Waard A 2005 Hisparc and minigrail
Int. J. Mod. Phys. A **20** 6884–6
- [29] Drayson Pilot Programme 2016 www.youtube.com/watch?v=dg84rVYiU-c
- [30] Telescopes in School 2017 <https://telescopesinschools.wordpress.com/>
- [31] IRIS: TIMPIX 2017 www.researchinschools.org/TIMPIX/home.html/
- [32] Chubb K, Hood R, Wilson T, Holdship J and Hutton S 2017 Discovering new variable stars at Key Stage 3 *Phys. Educ.* **52** 035011
- [33] The Cosmic Ray Detectives 2015 <http://sse.royalsociety.org/2015/cosmic-ray-detectives/>
- [34] Rocket Science Experiment 2016 <https://schoolgardening.rhs.org.uk/competitions/rocket-science-experiment-overview>
- [35] Hatfield P 2010 Using line intensity ratios to determine the geometry of plasma in stars via their apparent areas *High Energy Density Phys.* **6** 301–4
- [36] Blackawton P S *et al* 2011 Blackawton bees *Biol. Lett.* **7** 168–72
- [37] Tessenyi M, Tinetti G, Tennyson J, Savini G, Pascale E, Jason S, Liddle D, Williams J, Vora A and Saunders C 2015 Twinkle—a british space mission to explore faraway worlds *Proc. Int. Astronautical Congress vol 6* (International Astronautical Federation) pp 4311–3
- [38] Jason S *et al* 2016 Twinkle: a new idea for commercial astrophysics missions *The 4S Symp. Small Satellites Systems and Services Symp.* ed J Maruani and J Serre (ESA)
- [39] Tennyson J *et al* 2016 The ExoMol database: molecular line lists for exoplanet and other hot atmospheres *J. Mol. Spectrosc.* **327** 73–94
- [40] Tennyson J and Yurchenko S N 2012 ExoMol: molecular line lists for exoplanet and other atmospheres *Mon. Not. R. Astron. Soc.* **425** 21–33
- [41] McKemmish L K, Masseron T, Sheppard S, Sandeman E, Schofield Z, Furtenbacher T, Császár J A G and Sousa-Silva C 2017 MARVEL analysis of the measured high-resolution spectra of $^{48}\text{Ti}^{16}\text{O}$ *Astrophys. J. Suppl. Ser.* **228** 15
- [42] Chubb K L *et al* 2017 MARVEL analysis of the measured high-resolution spectra of acetylene *J. Quant. Spectrosc. Radiat. Transfer* **204** 42–55
- [43] Gunter C 2013 Science: it is a role model thing *Genome Biol.* **14** 105
- [44] Mernoff B, Aldous A R, Wasio N A, Kritzer J A, Charles H E and O’Hagan K 2017 A reverse science fair that connects high school students with university researchers *J. Chem. Educ.* **94** 171–6



Clara Sousa-Silva is a molecular astrophysicist and science communicator at MIT. Alongside her research where she looks into the habitability of planets, Clara works as an advocate for making STEM fields more inclusive. Clara lived in Scotland from 2005 to 2010 where she did her undergraduate and masters degrees at the University of Edinburgh—for her masters thesis, Clara

studied the dynamic effect of death of a star on its planetary system. In 2011 she moved to London and joined the *ExoMol project* (University College London) as a PhD student under the supervision of Professor Jonathan Tennyson. For her PhD, Clara simulated the spectra for the phosphine molecule with unprecedented breadth and accuracy.

In September 2016 Clara joined MIT as a post-doc in the *EAPS* department working with Professor Sara Seager on alien biosignatures. In the two years before Clara left London for Massachusetts, she was the Educational Co-ordinator for the *Twinkle Space Mission* and founder of *EduTwinkle*, the mission’s educational program. As part of *EduTwinkle*, Clara created the *ORBYTS* programme.



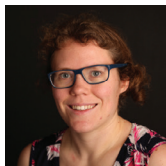
Dr Laura McKemmish coordinated the *EduTwinkle ORBYTS* programme in the 2016-17 year. She led *ORBYTS* teams at Highams Park School in the 2016 pilot and in 2016/17, and also coordinated and led the *ORBYTS Diatomic Constants (DC) Summer School* at UCL in August 2017 for

twenty-five pupils. In 2018, Laura will take up a Chemistry lectureship at University of New South Wales Australia. Laura is currently a Marie Skłodowska-Curie research fellow working with Prof Jonathan Tennyson at University College London. By training, she is a quantum chemist and molecular physicist, and enjoys using this expertise in innovative and interesting interdisciplinary projects, such as producing data for use in studying exoplanet atmospheres.



Katy Chubb has been a PhD student with the *ExoMol* group at UCL since September 2014. She studied Physics and Astrophysics at the University of Birmingham where she gained an interest in quantum mechanics and exoplanets, amongst other things. As part of *ExoMol*, Katy is working to provide theoretical data which will aid the characterisation of exoplanet and cool star atmospheres, focusing in

particular on the acetylene molecule. She got involved with *Twinkle* as an organiser of the *Origin of Life* exhibition at the 2015 Royal Society Summer Science Exhibition and has done a number of related outreach events since. She has been a team leader for the *EduTwinkle ORBYTS* programme since 2015 and is currently helping to evolve it further. She was one of the lead Astronomers for the pilot of the *Mayors Fund for London Astronomy Club*.



Dr Maire Gorman is a Team Lead for the EduTwinkle ORBYTS programme. She gained her PhD in 2016 as part of the ExoMol group where she calculated line lists for CrH and MnH, the former of which is crucial in modelling L-type Brown dwarfs. Prior to UCL, she studied Physics at Oxford University, specialising in Atmospheric & Astrophysics with a Master's project simulating X-ray spectra from Black Holes using the Monte Carlo method. Since January 2016 she has been a Teaching Fellow in the Physics department at Aberystwyth University where she teaches numerical methods, mathematical physics, planetary & atmospheric physics as well as year 0/year 1 undergraduate material. In addition to supervising undergraduate education/outreach projects she is also continuing her research into diatomic molecules by supervising projects involving undergraduates, Nuffield summer students and A-level students as part of the remote ORBYTS programme which she leads. She has also initiated and helped facilitate the expansion of The Brilliant Club to Aberystwyth University and the surrounding area.



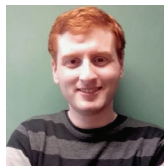
Jack Baker is a Team Lead for the EduTwinkle ORBYTS programme. Jack is a PhD student at the London Centre for Nanotechnology, UCL, undertaking ground-breaking research in the field of Computational Condensed Matter Physics. Quantum mechanical simulations are performed on systems of unprecedented size to probe the nature of ferroelectricity in nanoscale systems.

Formerly, Jack has worked at the UK's national particle accelerator, Diamond Light Source as well as having worked for McLaren Motorsport in the applied technologies sector. Jack also has a strong interest in teaching. He demonstrates in both first and second year laboratories on the topics of Practical and Computational Physics.



Emma Barton is a Meteorologist working at the Centre for Ecology and Hydrology since 2016. Her current research is looking to better understand the feedback between the atmosphere and land surface, with a focus on the Indian monsoon.

Prior to this she performed research in molecular physics and spectral modelling with application to industrial spectral studies and extrasolar planetary atmospheres. She was awarded her PhD in Physics and Astronomy by University College London in 2016. A record of her publications can be found on research gate.



Tom Rivlin is a PhD student working under Jonathan Tennyson. He graduated in 2015 from Imperial College with an MSci in Physics with Theoretical Physics. Currently, he is writing code to simulate heavy particle scattering using the R-Matrix methodology. He is also involved in outreach work with schools

via the ORBYTS project.



Jonathan Tennyson is Massey Professor of Physics at University College London (UCL). He studied Natural Sciences at Cambridge University specializing in Chemistry and obtained a DPhil in Theoretical Chemistry from the University of Sussex. After postdoctoral work in the University of Nijmegen and at Daresbury Laboratory, he joined UCL's Department of Physics and Astronomy

as a 'New Blood' Lecturer. He was elected a Fellow of the Royal Society in 2009.

Tennyson uses quantum mechanical techniques to study the theory of molecular collisions and spectroscopy. They study problems with a broad range of applications including to atmospheric physics and to fusion and technological plasmas. In the astrophysics area he leads the ExoMol project which supplies comprehensive spectral line lists for modelling the atmospheres of exoplanets and other hot bodies. He is heavily involved in plans for the Twinkle space mission for exoplanet characterisation